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High Intensity Illumination from Mantles

James P. Kottenstette
University of Denver

Technical Report AFATL-TR-67-173

OCTOBER 1967

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EGLIN AIR FORCE BASE, FLORIDA

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HIGH INTENSITY ILLUMINATION FROM MANTLES

James P. Kottenstette

FOREWORD

This final engineering report is submitted in fulfillment of the requirements of Air Force Contract AF 08(635)-6098. The work was performed under the direction of the Air Force Armament Laboratory, Illumination Branch, Air Force Systems Command, Eglin Air Force Base, Florida 32542; Project Engineer, Mr. Lawrence W. Moran (ATTI).

The Denver Research Institute personnel responsible for the work reported herein include J. P. Kottenstette, T. A. Espinoza, R. J. Fay, W. A. Schmeling and R. F. Marchese. The research effort was conducted at the Denver Research Institute, University of Denver, Denver, Colorado. Mr. W. S. Sease of the Welsbach Corporation was especially helpful in supplying mantle materials and hardware used in this investigation. The program began on 1 July 1966 and was completed June 30, 1967.

Information in this report is embargoed under the Department of State International Traffic in Arms Regulations. This report may be released to foreign governments by departments or agencies of the U.S. Government subject to approval of the Air Force Armament Laboratory (ATTI), Eglin AFB, Florida 32542, or higher authority within the Department of the Air Force. Private individuals or firms require a Department of State export license.

A. J. Cupper, Lt. Colonel, USAF Chief, Targets and Missiles Division.

This technical report has been reviewed and is approved.

A. J. CUPPER, Lt Colonel, USAF
Chief, Targets & Missiles Division

ABSTRACT

The potential of the Welsbach mantle as a means for producing high intensity illumination has been examined. Through the development of a vortex combustor geometry that drives the mantle, and the substitution of fuel-oxygen reactants for the normal fuel-air combination, the luminous intensity of the mantle was increased 30 to 50 times. An efficiency for the conversion of chemical energy to illumination of 0.2 candela/Btu-hr was achieved.

The mechanism for the production of light from a mantle was investigated by evaluating the changes in performance obtained with mantles having various thoria-ceria ratios. These studies lead to the proposal that the mechanism for light production lies in the combination of low emittance and high temperature rather than in a "high emissive power in the visible" as the phenomena have been described.

Various combinations of mantle arrays have been investigated in order to define the requirements for multiple mantle operation in compact configurations. This work was extended to the investigation of the oxygen-fired mantle in combination with a small reflector. The combination was used to generate a 10° cone of illumination in excess of 50,000 beam candlepower with an efficiency of four candlepower/Btu-hr.

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Section I

INTRODUCTION

This report summarizes an experimental development program that had as its objective, the evaluation of the potential of the Welsbach-type mantle as a source of high-intensity illumination. The program was based on the assumption that a mantle could be made to radiate more efficiently, and with a higher intensity, if it was operated at tempera. .res higher than those obtainable with fuel-air reactants. Preliminary experimentation, in which mantle was coupled with a vortical combustion apparatus[1] indicated that improved radiant output was obtained as a result of the premixed, forced combustion within the mantle volume. Further, it was noted that the addition of oxygen to the reactant feed (propane and air) resulted in increased illumination from the mantle. These results were the basis for the assumption, and the experimentation was organized to give dimension to the process of light production with a vortex-driven mantle.

The gas fired mantle - the Welsbach mantle - has a historical significance in the production of light using hydrocarbon fuels as the energy source. A commercial mantle, operated n ..ally, will produce approximately one candela at a fuel rate of 25 Btu/hr. Larger mantles, having relatively larger surface areas can be made to operate at approximately two candela per 25 Btu/hr input. This difference is the result of a complicated trade-off between increased surface area and decreased operating temperature, and as such, has a distinct maximum. The total illumination from a specific mantle size can be increased by increasing the fuel rate, but this is accompanied by a sharp decrease in efficiency; i.e., a candela increase by a factor of four can be obtained with an eightfold increase in fuel consumption. This approach is also self-limiting because of the increased volume of products that must stream through the mantle. This product flow must become turbulent at some flow rate and the turbulence will destroy the mantle.

Since the presence of nitrogen in the oxidizer flow acts to increase the total volume of the combustion products and to reduce the

[1] J. P. Kottenstette and R. J. Fay, "The Feasibility of Utilizing the confined Vortex as a Means of Signature Generation", Part II AFATL-TR-66-63, July 1966.

flame temperature of the reaction, the basic task was to develop a combustor geometry to drive the mantle that could be operated with oxygen comprising the total oxidizer flow. The physical characteristics and design limitations on such a combustor are described in Section II. The combustor geometry evolved as dictated by the achievement of greater and greater luminous intensities from a "control" mantle geometry. This evolutionary process involved four stages of combustor modification, each improving on some facet of the excitation process. A paradox that existed in the conduct of the program can now be seen. Since there was no generally accepted definitive theory that describes the "mechanism" of mantle performance, it had to be assumed that any modification in the combustor design that would raise the flame temperature would be useful in increasing the luminous intensity obtained from the mantle. This was found to be the case: by developing the techniques necessary to obtain high product flow rates, an oxygen-fired mantle can be made to generate 30 to 50 times the illumination obtainable with an air-fired mantle.

Paralleling the development of the combustor, a continuous effort was maintained toward a better understanding of the role played by the mantle in the generation of radiation. This experimentation, presented in Section III, included visible and infrared spectroscopy, mantle composition variation, product mass spectrometry and temperature determinations. These studies have given the necessary insight into the "mechanism" of mantle performance and have formed the basis for a modified theory of mantle performance which is presented in Section IV.

The modified theory of mantle operation forms the basis for a recommended course of investigation to improve the luminous intensity obtainable from the mantle still further, and suggests the ultimate limits in mantle performance that can be expected. These recommendations and the other experimentally-derived conclusions are presented in Section V.

Section II

DEVELOPMENT OF THE VORTEX COMBUSTOR

In the initial stages of the experimentation, premixed propane and air was expanded into a vortex tube that was approximately two inches long and 1/4-inch in diameter. A mantle (Welsbach #846, pictured in Figure 4) was positioned at the end of the tube and the apparatus was oriented so that the mantle was upright. The mantle could be excited in this manner such that as the luminous intensity ranged from 50 to 200 candela, the luminous efficiency decreased from 0.04 to 0.02 candela/Btu. This performance indicated that the exit temperature for the products of reaction (corresponding approximately to the temperature of the mantle) was raised as the throughput was increased. However, since the flame temperature was essentially constant (a function of the mixture ratio only because the combustion process was highly complete within the mantle volume for the reactant rates employed), the temperature difference between the flame temperature and the mantle temperature decreased; hence the decrease in efficiency with increased luminous intensity. The initial attempt to introduce substantial oxygen into the air flow, as a means of raising the combustion temperature, was a failure because the combustion velocity of the mixture was increased to the extent that the reaction occurred within the vortex tube. This deleterious effect initiated the concept of the double vortex combustor.

A. The Double Vortex Combustor

The double vortex combustor was conceived to meet a set of requirements that were recognized as a result of the initial experimentation. These requirements were imposed by the physical characteristics of the mantle itself, and they can be better understood if the important characteristics of the mantle are identified. The mantle characteristics that affect combustor design are:

1. The cylindrical shape of the mantle. The mantle is excited by reactant flow into one end of a cylinder that is closed at the other end. A high axial velocity imparted to the reactants would effectively excite only the closed end of the mantle and not the sides.

The requirement: generate a combustion flow field in which there is a radial as well as axial velocity component.

2. The porosity of the mantle. The mantle construction offers little confinement and therefore is a poor reaction chamber. The static pressure measured within the mantle shell (a Welsbach #848) was approximately 0.01-inch of water at the maximum firing rate employed (13,700 Btu/hr).

   The requirement: create an extremely small combustion volume that is maintained by aerodynamic forces. These forces would complement the confinement offered by the mantle shell and improve the degree of reactedness in the flow streaming through the mantle fabric.

3. The structural nature of the mantle. The mantle is constructed of short ceramic fibers that interlock mechanically. It is this feature that accommodates the thermal shock loadings generated when the mantle is fired. While the mantle appears fragile, the interlocking nature of the fibers actually makes the shell extremely rugged because the surface can be deformed without failure occurring. Further, when local failure is experienced, the disturbance does not propagate as it would if the surface were continuous. However, a highly turbulent combustion field adversely affects mantle life because of a fatigue effect associated with continuous flexing of the mantle surface.

   The requirement: maintain a nonturbulent combustion field.

The first and third requirements imposed a set of constraints on the method of mixing the reactants in the combustor. In normal engineering practice, a flame is isolated from the mixing chamber by creating a region between the flame and the chamber in which the reactant velocity is greater than the propagation velocity of the flame. This condition is normally achieved by forcing the reactants through small orifices. This approach was not feasible because the limited cross section in the mantle base coupled with the large reactant throughput would force a condition of high centerline velocity and turbulence. The second requirement, the small combustion volume,

dictated the use of the vortical combustion field since it has been well established that this flow field minimizes the required combustion volume.[2]

Figure 1 shows the four combustors that were used in the program. Designs one through three show the essential feature of the double vortex combustor, that of concentric vortex tubes which intrude into the mantle base. Design #1 provided the necessary experience to show that counter-rotating vortical flow fields create a combustion zone that meets the requirements outlined. Design #2 was a refined geometry that was used in the bulk of the mantle testing and is described in detail below. Design #3 was used in experimentation in which an array of mantles was operated simultaneously. This geometry was found to be slightly superior to Design #2 because the thermal feedback to the combustor was much less.

Design #4, the floodlamp combustor, was a hybrid unit designed for operation in a small reflector. Both of these units, #3 and #4, are discussed in Part B of Section III in which relevant experiments are described.

B. Combustor Performance

Figure 2 shows a comparison among the three combustor designs in terms of efficiency and total candela output obtained from the excitation of a commercial mantle geometry and composition (Welsbach #846). The units were operated with propane and oxygen reactants up to a fuel rate of 13,700 Btu/hr. The data indicate that the performance obtainable with a mantle is sharply dependent on the details of the combustor geometry and the mantle coupling to that geometry. These details are presented in terms of Design #2.

Figure 3 shows the construction of this counter-rotating, double vortex design (see Appendix I for line drawings). The oxidizer flow is expanded into the inner vortex tube (the tube attached to the center element in the figure), and the fuel is expanded into an annular volume formed by the inner tube and the wall of the water jacket. The assembled unit, together with the "control" mantle geometry (Welsbach #846) is presented in Figure 4 in actual size.

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[2] Kottenstette and Fay, op cit p. 15

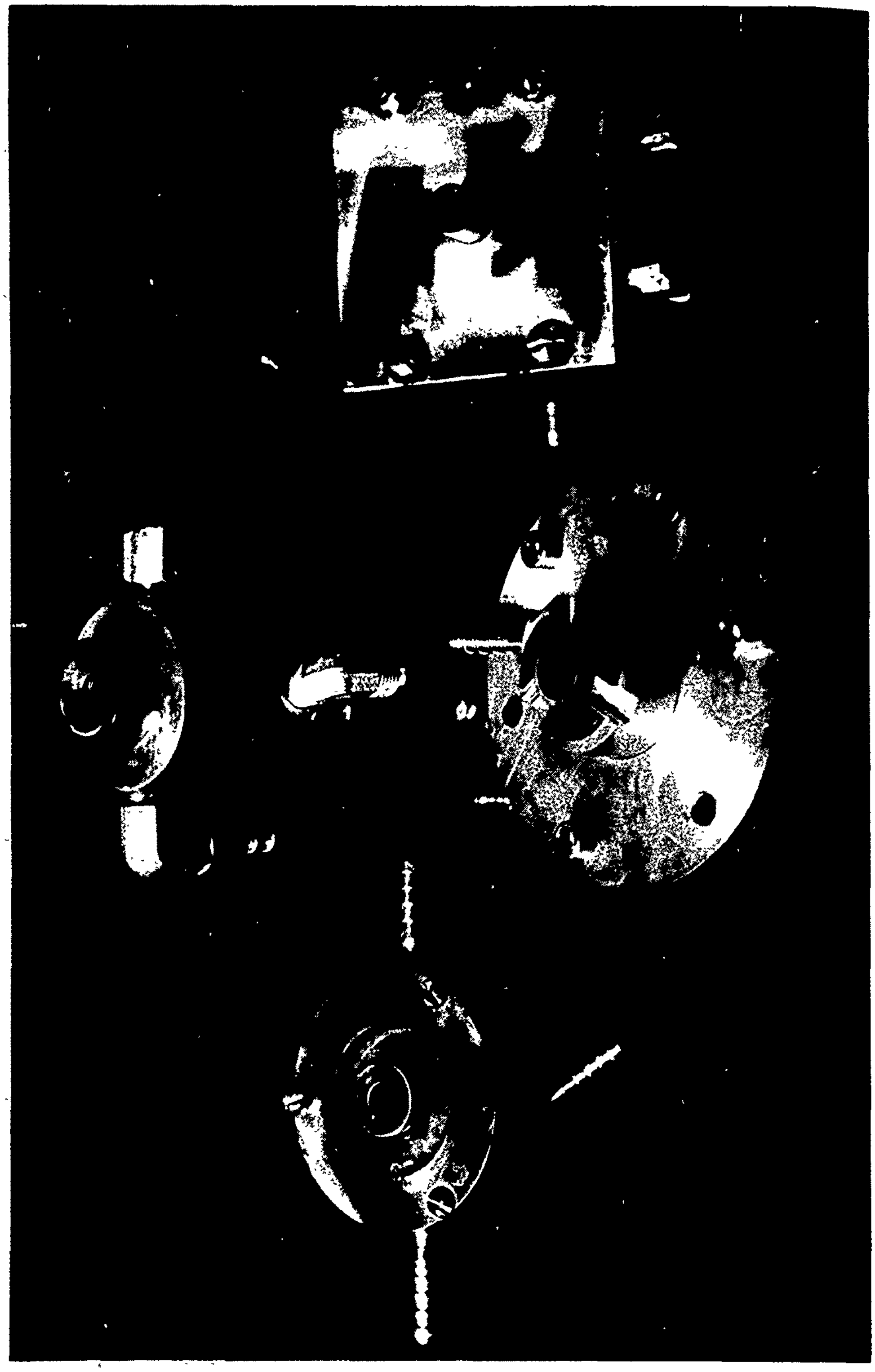

Figure 1. Combustor Configuration

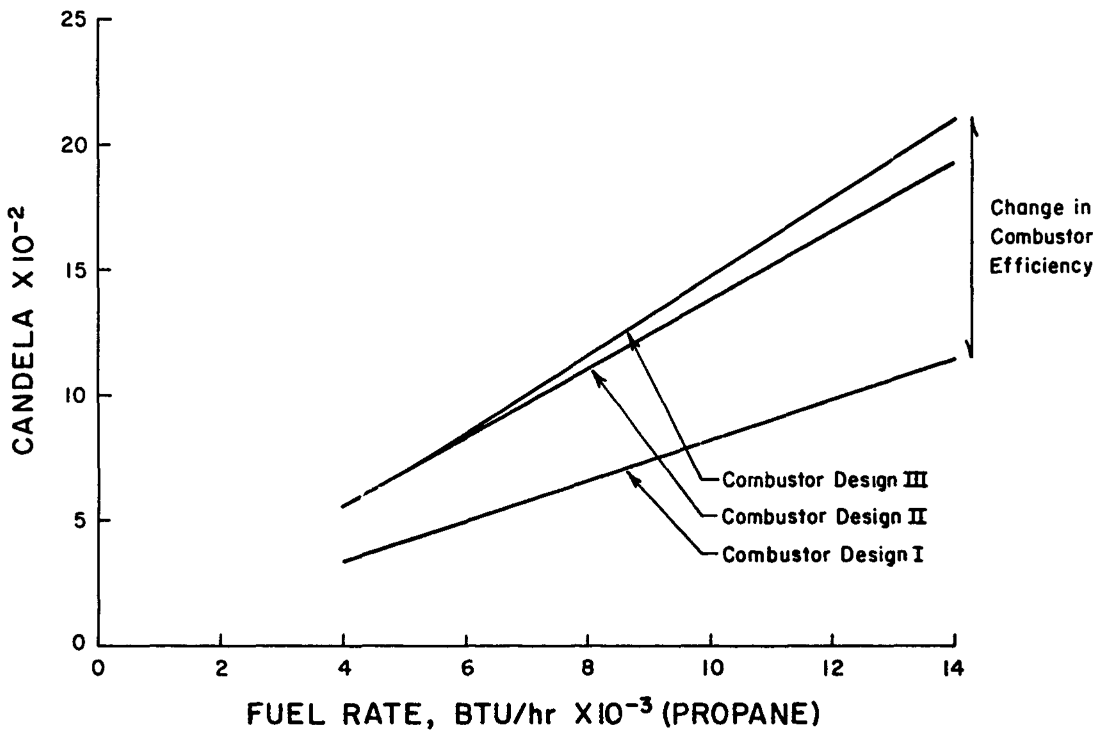

Figure 2. Mantle Performance (#846) Showing Effect of Combustor Modifications

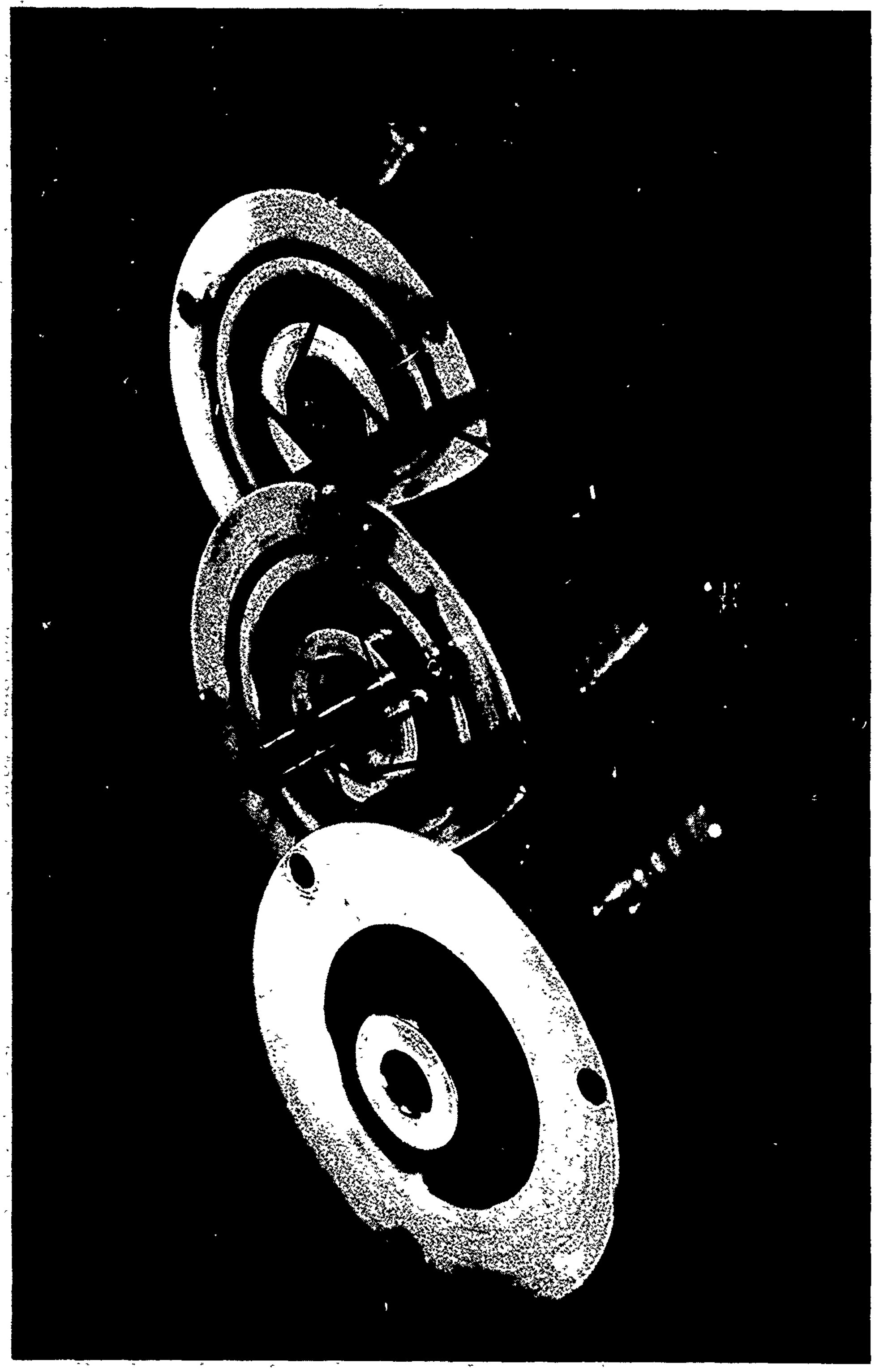

Figure 3. Internal Features of Design #2

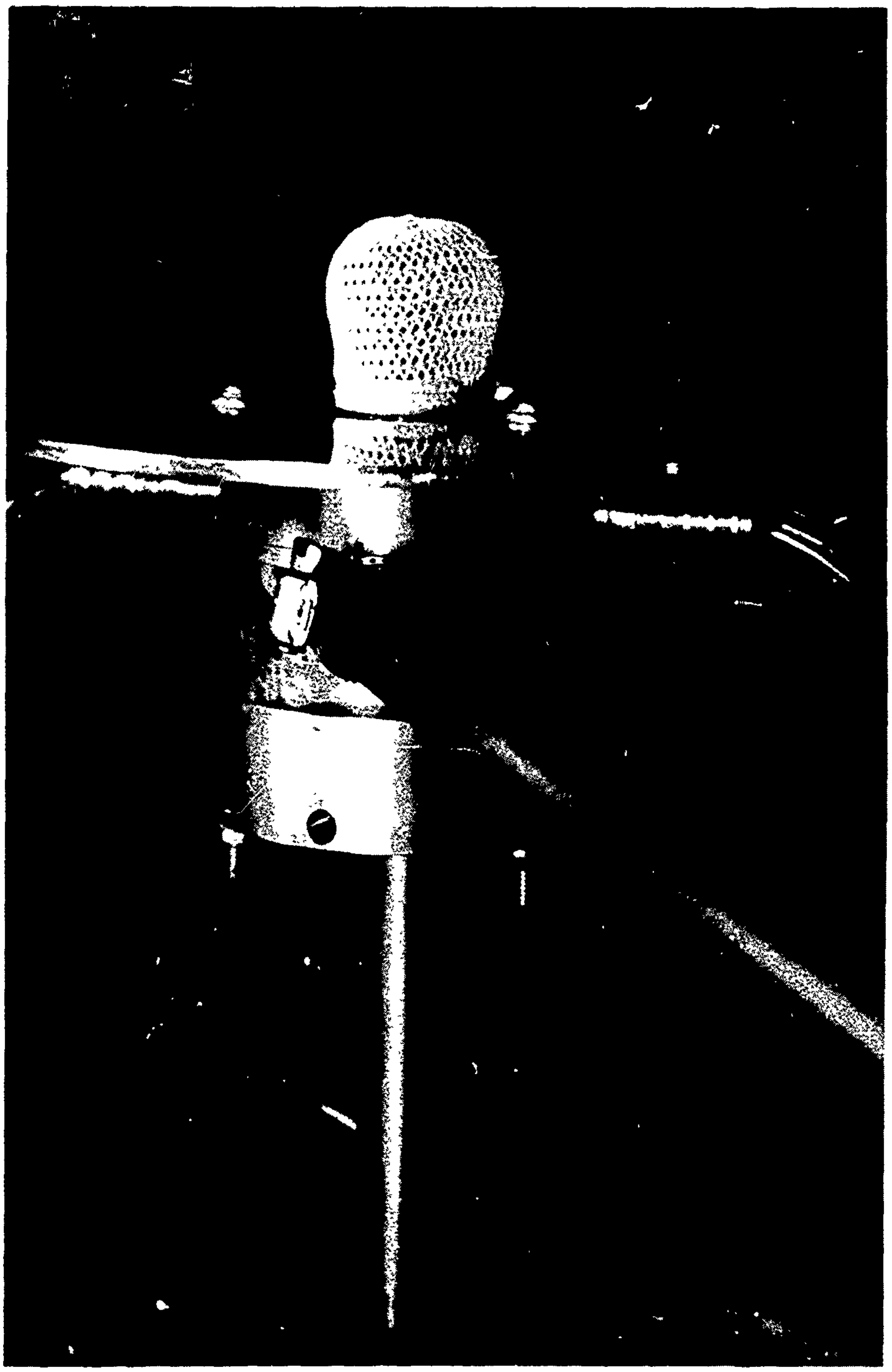

Figure 4. Overall View of Combustor and #846 Mantle (actual size)

Figure 5 shows the detail of the combustion zone when the unit is operated at a fuel rate of 13, 700 Btu/hr (propane) and with stoichiometric oxygen flow. Since the oxygen flow is approximately five times greater than the propane flow, and is also expanded into a smaller diameter vortex tube, the central vortex is more intense.[3] This condition draws the fuel into the oxygen vortex and enhances the mixing obtained. The central region of the flame is one of low pressure that is caused by the radial component of the product velocity. This effect is minimized in the photograph presented because ambient air is also being drawn into the outer boundary of the flow field and this induction of air acts to reduce the radial expansion. This is not the case when the mantle is in place since the static pressure inside the mantle is greater than ambient pressure. The reaction zone inside the combustor is isolated from the nozzle wall by a thin sheath of unreacted fuel. This sheath prevents convective heat transfer to the outlet of the combustor, and can be seen in the photograph together with its subsequent reaction in the inducted air stream.

The last essential feature of this combustor design is that a residual circulation is maintained within the mantle volume by the action of the central vortex. This circulation sweeps the products of combustion around the inner mantle surface and makes the excitation of the mantle more uniform. This action increases the residence time of the reactants and thus improves the degree of reaction completion achieved in the excitation process.

Figure 6 presents a schlieren photograph of a Welsbach #848 mantle operating at approximately 1000 candela. This photograph shows the lack of turbulence in the combustion process and indicates the residual circulation, described above, by the shape of the plume above the mantle.

One of the main operating concepts that applied to all combustor designs was the use of low pressure to drive the reaction. The importance of low pressure operation is tied to the possibility of supplying the combustor with reactants that are stored under their own vapor

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[3] If the outer vortex is made the more intense of the two, the flame will form a flat disk that attaches to the top of the combustor and expands radially.

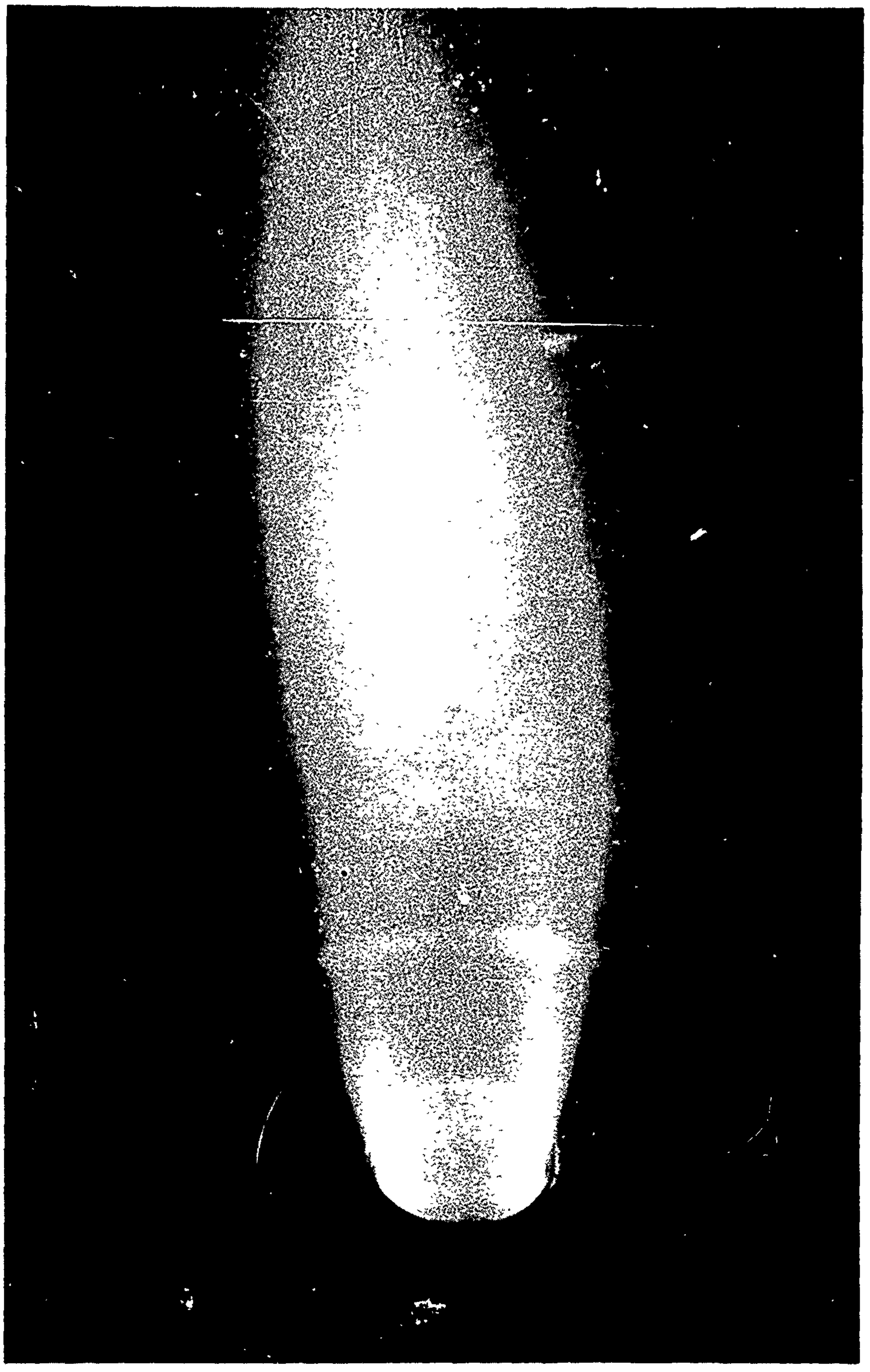


Figure 5. Flame Characteristic at 13,700 Btu/hr

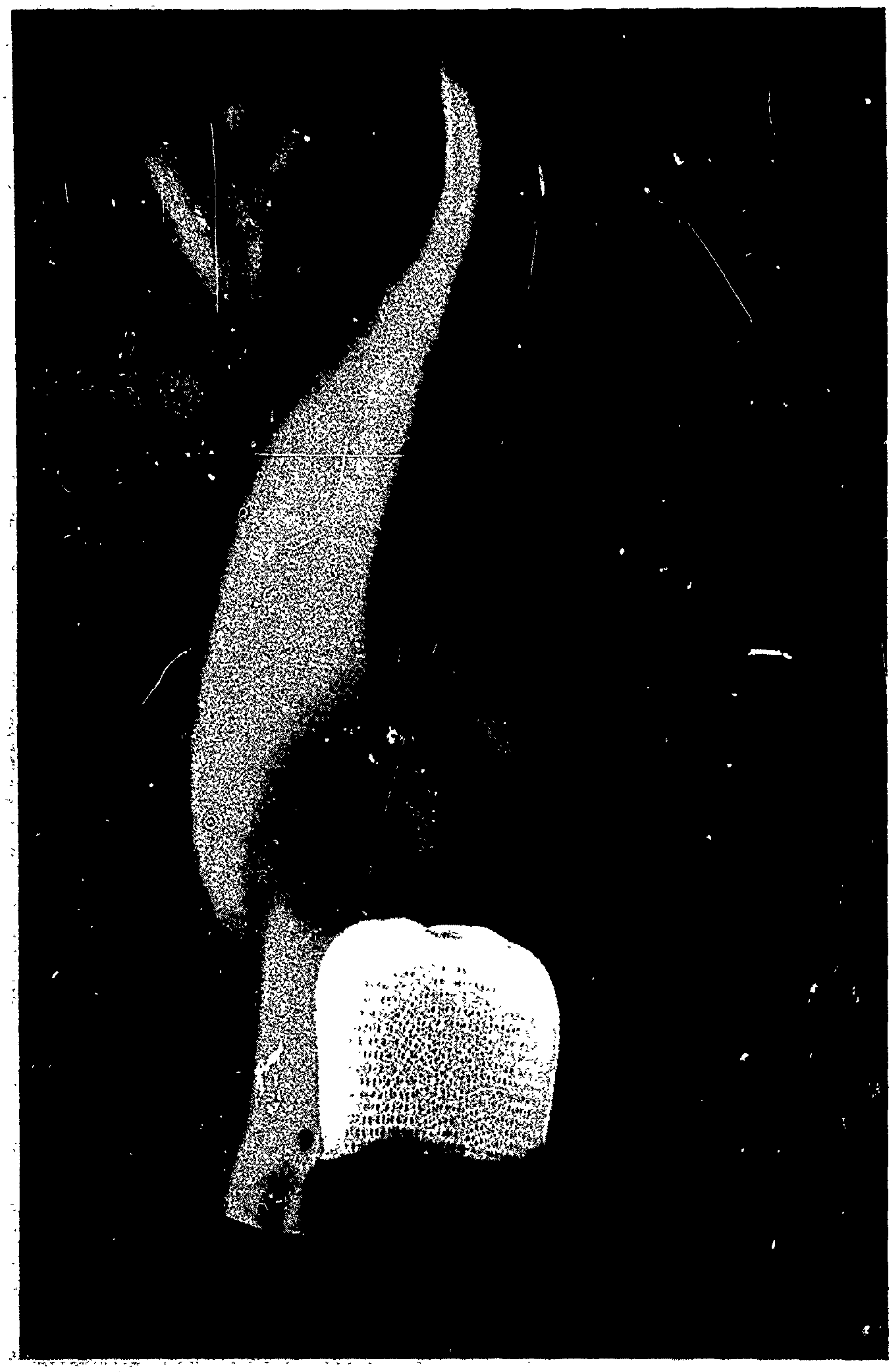


Figure 6. A Schlieren of the Mantle in Operation shows lack of Turbulence

pressure. Further, low pressure operation offers reduced hazard in the event of a mechanical failure. Finally, the engineering design for multiple combustors in the creation of high intensity sources is facilitated by low pressure operation. The operating pressures for Designs #2 and #3 were 3 psig for the oxygen and 0.25 psig for the propane at a fuel rate of 13,700 Btu/hr. These values are low enough to permit operation over the wide range of temperatures that might be encountered in the storage of the L.P.G. fuels and also permit the non-hazardous storage of liquified oxygen which could be vented at approximately 5 psig. The principle difference between combustor Design #2 and Design #3 was the use of a ceramic bushing to close the base of the mantle when it was operated with Design #3. In Design #2, the mantle was positioned over a brass protrusion that acted to inhibit gas flow out the mantle base. This protrusion which formed the nozzle for the combustor was fully exposed to the hot gases within the mantle. Figure 7 shows the heat transfer to the respective combustor designs as a function of input power. The reduction in heat transfer in the case of Design #3 was obtained by fitting the extended portion of the vortex tube with a ceramic ring that was the same size as the inner diameter of the mantle base. In this manner, a path of high thermal impedance was created so that the reaction was more effectively isolated from the combustor. The reduction in heat transfer is credited for the improved performance of Design #3 (see Figure 2).

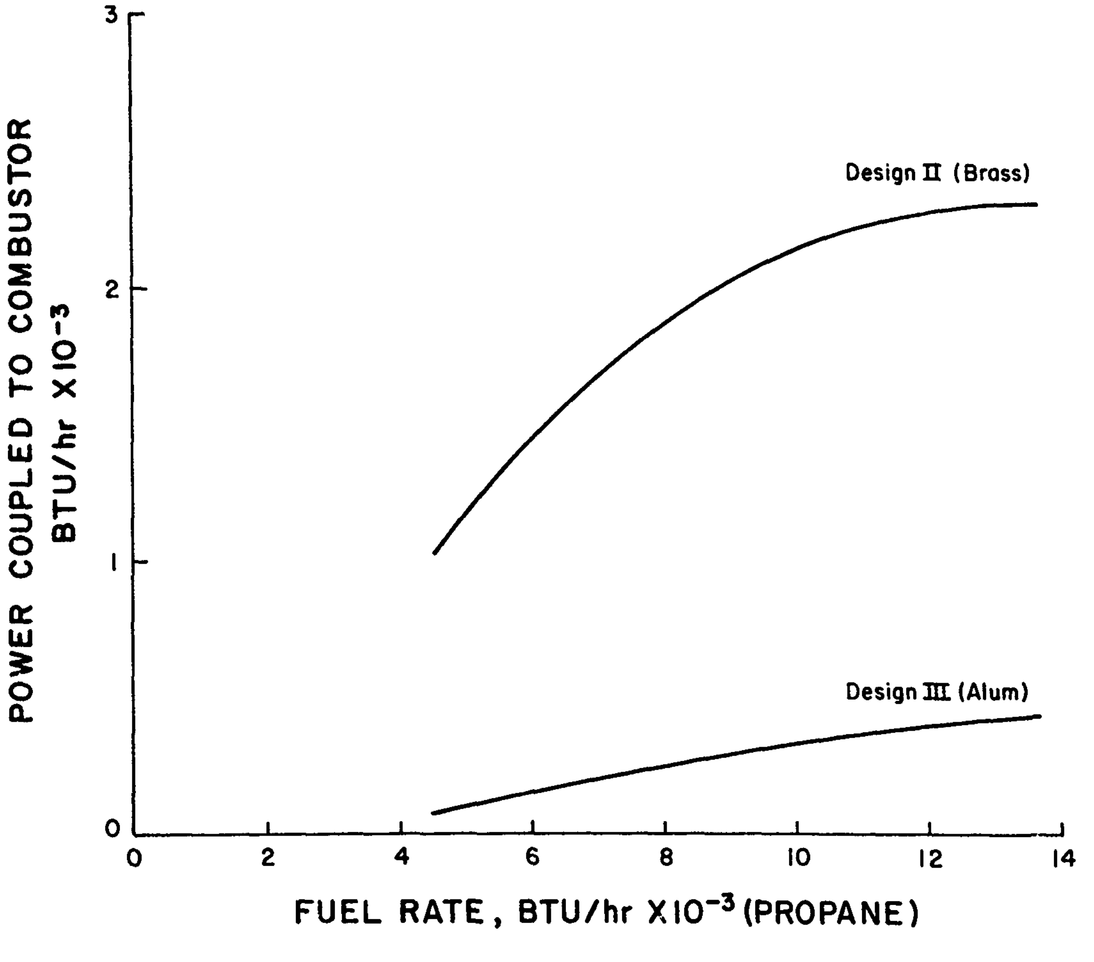


Figure 7. Heat Transfer to the Combustors as a Function of Fuel Rate

Section III

MANTLE PERFORMANCE

The experimentation that probed the "mechanism" of the mantle's luminous intensity centered on studies of four different mantle compositions. This effort was organized to define the conditions associated with specific levels of mantle performance. Using this approach, the knowledge of conditions associated with a given performance level could provide a basis for mantle utilization regardless of the success achieved in "mechanism" definition. The value of this approach can be appreciated when it is considered that a single mantle (#848), used in conjunction with a commercial reflector, can be operated to obtain a 10° cone of illumination in excess of 50,000 beam candlepower. Application experiments of this type are discussed in Part B of this section.

A. Composition Studies

The bulk of the experimentation conducted in these studies utilized combustor Design #2 although some work using Design #3 will be reported. The mantles used were primarily the commercial Welsbach #846 and #848 styles. These mantles are composed of thorium oxide with a trace (approximately 0.7 percent) of cerium oxide added. To complement the study of this composition, a family of mantles was compounded that had 5, 10, and 20 percent cerium oxide, by weight. These mantles were identical to the standard Welsbach #846. This type mantle has the "Hill" weave and is fired and hardened in manufacture. An analysis of these mantles by X-ray (Debye-Sherrer Powder diffraction method) showed that the cerium oxide was in solid solution with the matrix of thorium oxide for each mantle composition. The patterns were very clean, indicating a lack of impurities although some background scatter was seen in the higher cerium oxide content samples. The results of this analysis are presented in Table I.

The independent variable in all the testing with propane was the fuel rate: for a test, the fuel rate would be established and the oxygen flow adjusted to maximize the candela generated by a mantle. Brightness temperature, total radiation, and spectral distribution were then recorded as functions of fuel rate. The candela values reported were normally measured by viewing the side of the mantle and recording the foot-candles obtained at a specific distance (seven feet). These candela

TABLE I. CERIA CONTENT AS A PERCENTAGE OF THE ThO_2 - CeO_2 MIXTURE

	X-Ray Analyses*	
Nominal Value	(by Volume)	(by Weight)
1	1	0.7
5	6	4.5
10	12	9.2
20	26	20.4

*All samples were taken from mantles that had been extensively operated.

values must be understood in the context that a spherical source of "x" candela would generate the measured illumination. A description of the foot-candle meter and the other instrumentation is included in Appendix II.

When operating the mantles on hydrogen, the fuel rate was also used as the independent variable, but a procedural change had a great influence on the control of this variable: the oxygen flow rate was established by the experimentation using propane. This was done to facilitate comparison between fuels. With the oxidizer rate thus set, hydrogen was introduced into the vortex combustor to obtain maximum candela. This procedure resulted in fuel-rich combustion and the least efficient operation, but did not mask the marked superiority of hydrogen as a fuel.

1. Experimental Results Using Propane Fuel

Table II presents a set of data obtained from the four mantle compositions of the type #846 and of the single composition (one percent ceria) in the larger mantle, type #848 There are several points worth particular attention in the tabulation.

1. The superiority of the type #848 mantle in both efficiency and total output.[4]

[4]The #846 and #848 mantle performances for the one percent ceria compositions are presented graphically in Figure 8.

TABLE II. MANTLE PERFORMANCE DATA

	Propane Fuel Rate Btu/hr				
Mantle Type	4500	6700	9000	11, 300	13, 700
#846 1% Ceria					
Candela	580	980	1330	1560	1800
O/F Ratio	4.7	5.8	5.4	5.1	5.0
Temp. °K	2020	2200	2280	2350	2430
#846 5% Ceria					
Candela	445	800	1160	1470	1740
O/F Ratio	4.8	4.9	4.9	5.4	5.4
Temp. °K	2040	2100	2160	2280	2380
#846 10% Ceria					
Candela	330	710	1190	1420	1740
O/F Ratio	6.4	5.7	5.4	5.9	5.3
Temp. °K	1900	2120	2220	2260	2370
#846 20% Ceria					
Candela	160	356	635	960	1290
O/F Ratio	6.7	6.2	5.9	5.7	5.8
Temp. °K	1930	2010	2130	2270	2350
#848 1% Ceria					
Candela	575	1200	1600	1960	2580
O/F Ratio	413	4.4	4.4	4.8	4.3
Temp. °K	1950	2110	2180	2210	2300

2. Brightness temperature increases with the fuel rate, but decreases with higher ceria content.

3. The small mantles tend to operate with a lean mixture while the large mantle tends to operate fuel rich.[5] The higher the ceria content, the leaner the mixture. In all cases, however, the mixture tends toward the stoichiometric at the higher fuel rates. This fact suggests that the different mantle compositions approach the same operating temperature as the fuel rate is increased (particularly the 1, 5, and 10 percent ceria mantles).

4. The difference between the performance of the 1, 5, and 10 percent ceria mantles is relatively small, but is much more pronounced at the lower fuel rates. The higher ceria content mantles generate light with yellow cast at the lower fuel rates, but the effect diminishes as the fuel rate is increased.

These data may be considered as conservative indicators of mantle performance. This set of data was tabulated because the same mantle was used for each determination in a given composition class. Numerous other test sequences were performed in which candela values of 2000 were obtained for the one percent mantle at a fuel rate of 13,600 Btu/hr (particularly with combustor Design #3).

Variations in performance were encountered with each mantle of a specific type. This variation was due principly to the age of the mantle (in terms of previous operating history), and to the shape the mantle assumed under operating conditions which affected the size of the presented area of the radiating surface. These variations seldom exceeded ±10 percent of those values tabulated and the tendency was toward the plus side. A new mantle, operated for the first time at a specific fuel rate would always exceed the tabulated performance.

[5]The stoichiometric oxygen to propane ratio is 5.0.

The mantle composition studies may be summarized in the following tabulation:

TABLE III. COMPOSITION STUDY SUMMARY (PROPANE FUELED)

Composition and Type		Input Btu*/hr/candela
1%	#846	7.5
5%	#846	8.0
10%	#846	8.0
20%	#846	10.5
1%	#848	5.3

*Measured at 13,700 Btu/hr input

A more detailed comparison of the one percent ceria mantles #846 and #848 is presented in Figure 8. These data, obtained with combustor #3, also show the relationship between an increase of mantle volume and the oxidizer/fuel ratio. The smaller mantle (#846) is characterized by an O/F ratio associated with the highest flame velocity while the larger mantle tends to operate with an O/F ratio producing the highest flame temperature.[6] The fall-off in performance at the highest fuel rate for the small mantle also suggests that the input fuel rate is too large for the fixed combustion volume offered by the mantle. This condition was not achieved in the operation of the larger mantle with propane; however, it was encountered in the mantle operation with hydrogen at higher fuel rates. This effect is discussed in Part B of this section. These results are complemented by the fact that the larger mantle operates at a brightness temperature somewhat lower than that of the small mantle (some 80 degrees centigrade). This temperature drop is forced by the excitation of a larger surface area[7] with a comparable fuel rate. At the operating temperature of the mantle,

[6] I. I. Berenblut and A. B. Downe, "Table for Petroleum Gas/Oxygen Flame", London, Oxford Press, 1960.

[7] The projected areas of the mantle are, respectively, 0.94 in^2 for the #846 and 1.75 in^2 for the #848.

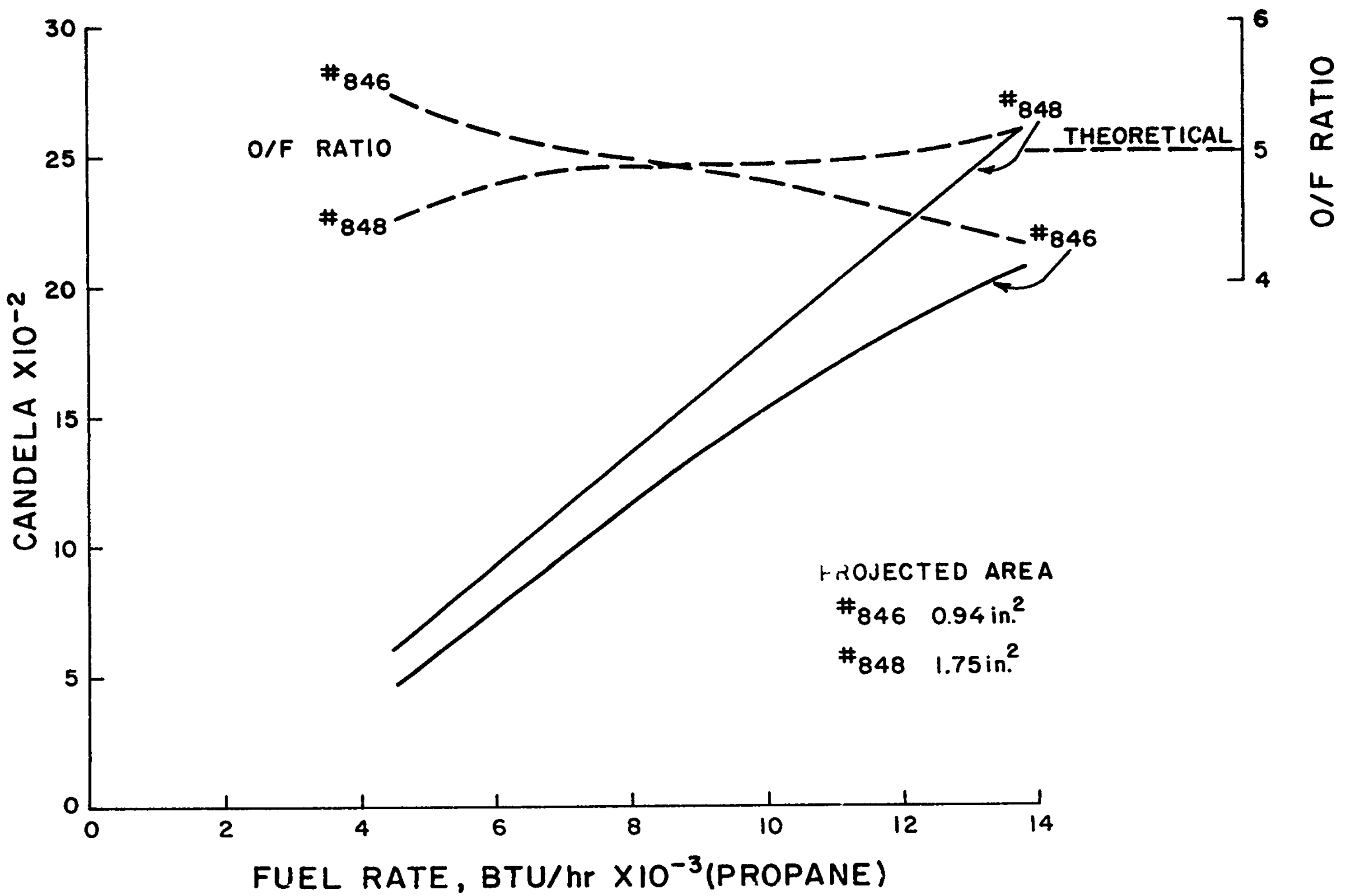


Figure 8. Performance Comparison of #846 and #848 Mantles

the candela output is proportional to the 10th power of the temperature; hence the ratio $(T + 80°/T)^{10}$ < Area (#848)/Area (#846) and more output is achieved from the #848. If, however, the temperature drop was approximately twice that actually obtained, the effect of increased area would be completely offset.

2. Experimental Results using Hydrogen

The substitution of hydrogen for propane had a substantial effect on the specific performance of all the mantles studied. Figures 9 and 10 illustrate the superiority of hydrogen fuel most clearly. The experiment that generated the data shown in these figures relied on the substitution of hydrogen for propane once the propane performance was established. The procedure was:

1. Set the propane fuel rate
2. Add oxygen to maximize candela
3. Replace the propane with hydrogen (the mantle was continuously operated)
4. Add hydrogen to maximize candela
5. Repeat the sequence at a higher propane rate

Figure 9 presents the propane performance obtained from the above experiment and Figure 10 the hydrogen performance. All of the #846 mantle compositions performed better using hydrogen at the lower fuel rate with the exception of the 20 percent ceria mantle. For this mantle the performance was essentially the same with either fuel. At the higher fuel rates, the performance was better, but the increase less significant. The experimental procedure employed forced the hydrogen reaction to be fuel-rich and for this reason these performance values are conservative. The stoichiometric oxidizer to fuel ratio for the oxygen-hydrogen reaction is 0.5; the ratio obtained in these performance tests was approximately 0.35. This condition was explored by comparing the performance of the #846 mantle with that of the #848 mantle. These data are presented in Figure 11. It was found that the reaction tended to run rich at the lower fuel rates, but moved toward the stoichiometric value at the higher fuel rates. The more favorable stoichiometry in the run on the #846 mantle is responsible for the improved performance as compared to the same mantle in Figure 10. The shape of the performance curve of the small mantle shows the same

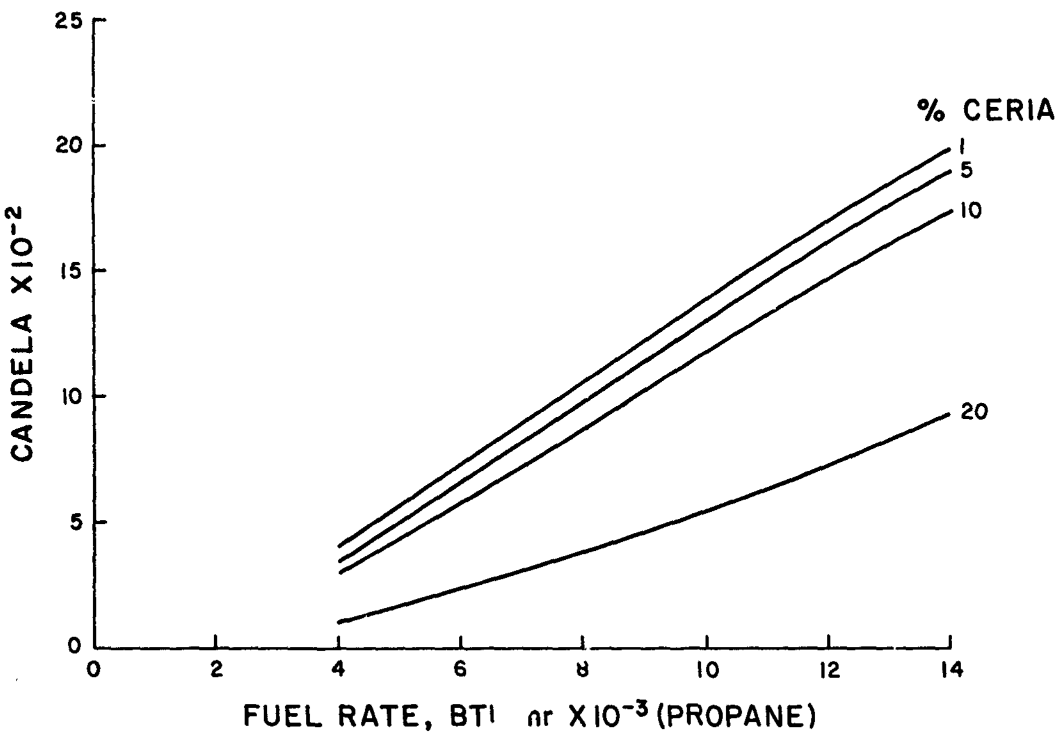


Figure 9. Performance Curves for the Four Welsbach Mantle Compositions Style #846 (Hill Weave) Luminous Intensity Versus Fuel Rate (Propane)

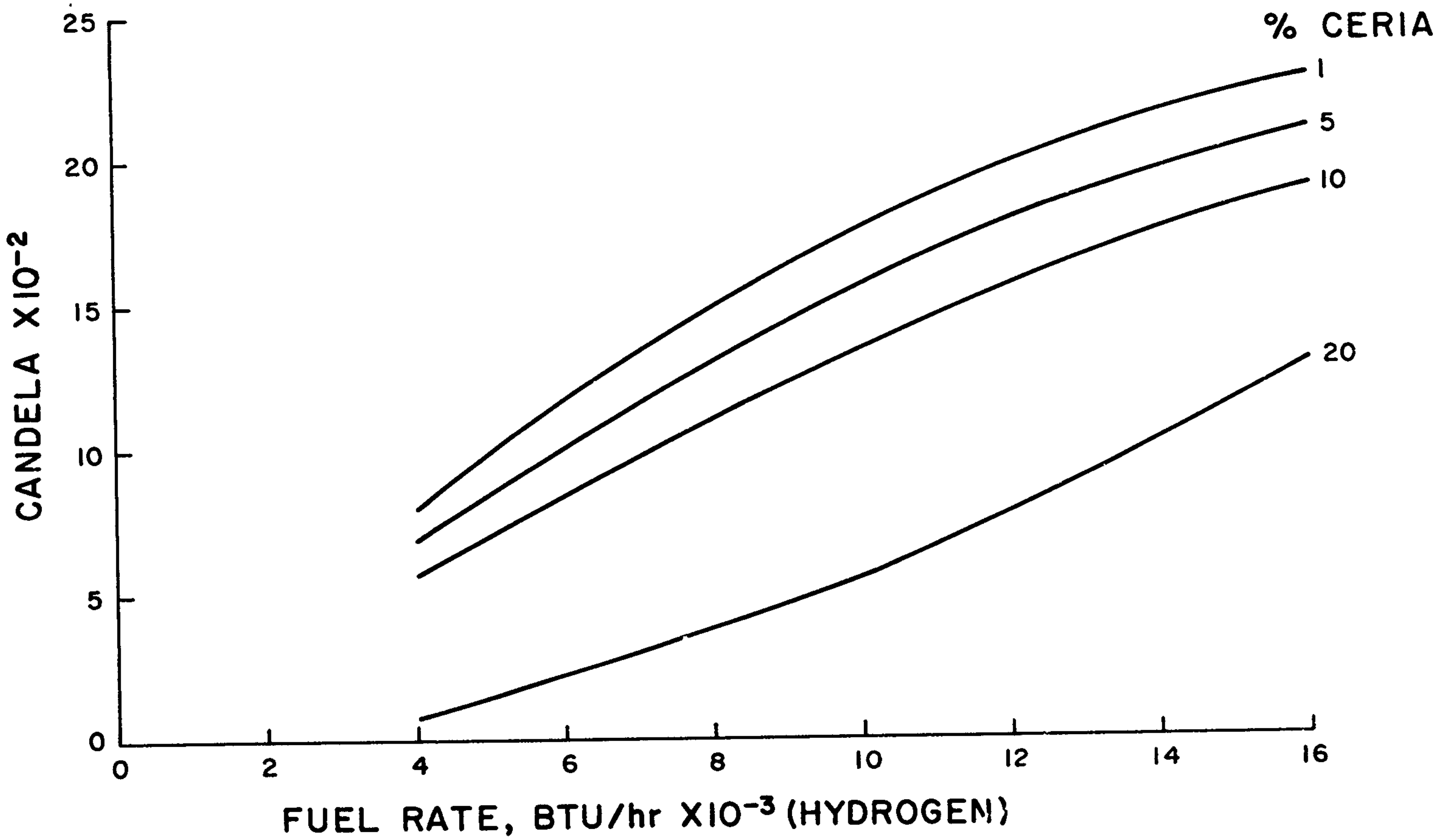


Figure 10. Performance Curves for the Four Welsbach Mantle Compositions Style #846 (Hill Weave) Luminous Intensity Versus Fuel Rate (Hydrogen)

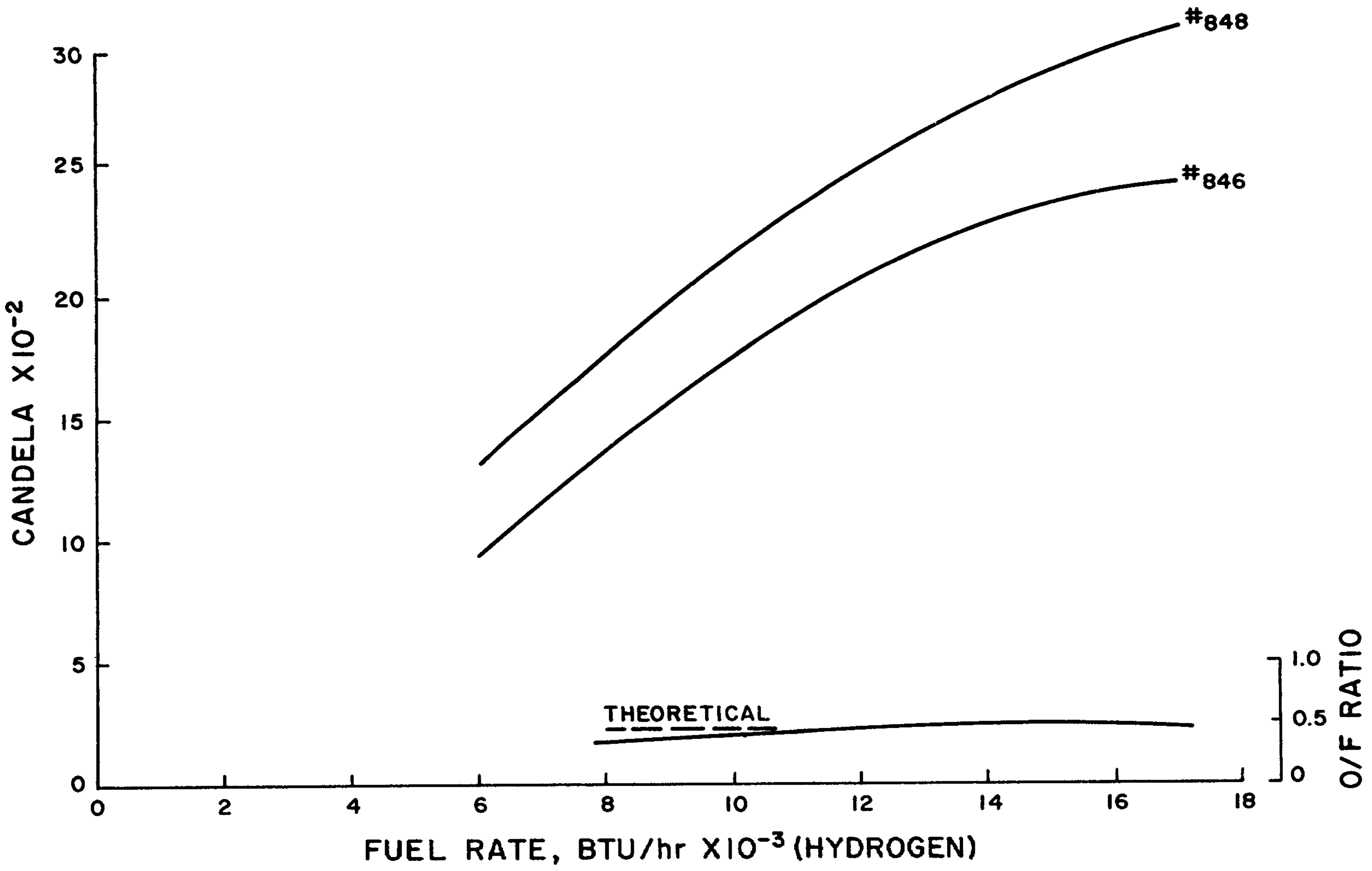


Figure 11. Performance Comparison of #846 and #848 Mantles

characteristic that was observed with propane; i. e., a fall-off in performance at the highest fuel rate (see Figure 8). This is consistent with the interpretation that the fuel rate has exceeded the required combustion volume as defined by the #846 mantle. The highest intensity and the maximum efficiency were again obtained with the #848 mantle. The maximum candela obtained from this mantle geometry, for an extended period of operation, was 3500 candela at a fuel rate of 22, 000 Btu/hr. The efficiency for the conversion of chemical energy to radiant energy is somewhat lower at this operating point than that obtained at 12, 000 Btu/hr; i. e., 6. 3 Btu/hr/candela versus 4. 8 Btu/hr/candela. The efficiency of 4. 8 Btu/hr/candela corresponds to 10, 000 candle-sec/gm of reactants.

The performance of the mantles using hydrogen as the fuel is summarized in Table IV.

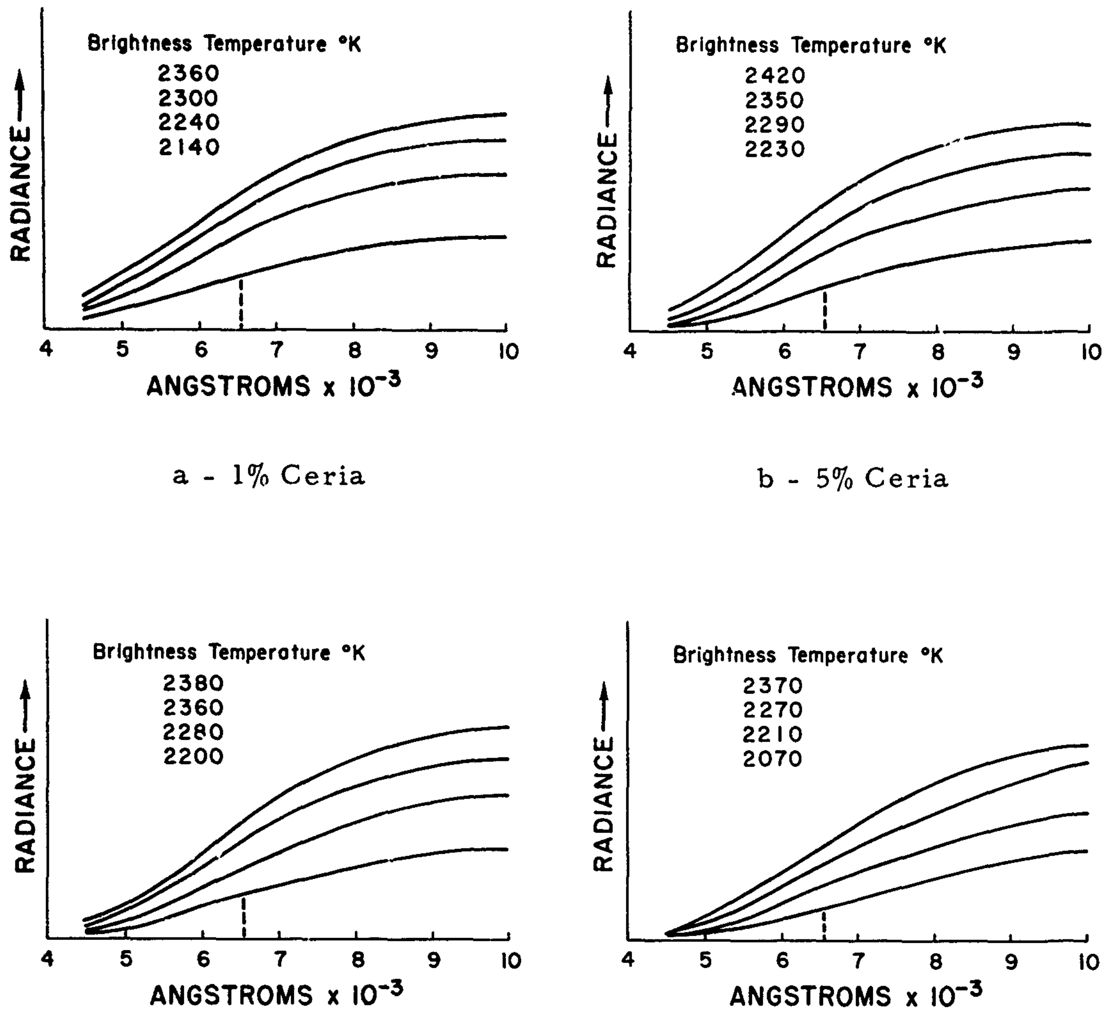
TABLE IV. COMPOSITION STUDY SUMMARY (HYDROGEN FUELED)

Composition and Type		Input Btu*/hr/candela
1%	#846	6. 1
5%	#846	7. 0
10%	#846	8. 0
20%	#846	13. 7
1%	#848	5. 0

*Measured at 13, 700 Btu/hr input

3. Spectral Distribution of Mantle Radiation

The spectral distribution of the radiant energy generated by the ... .ily of mantle compositions was determined for the visible and near IR portion of the spectrum and then for the infrared region of the spectrum (1 to 5. 5 microns). The data from these experiments are presented in Figures 12 to 15. The objective in these experiments was to generate information on the effect of increased ceria concentrations on



a - 1% Ceria

b - 5% Ceria

c - 10% Ceria

d - 20% Ceria

Figure 12. Spectral Distribution Obtained from 1%, 5%, 10% and 20% Ceria Mantle when Operated at Various Fuel Rates

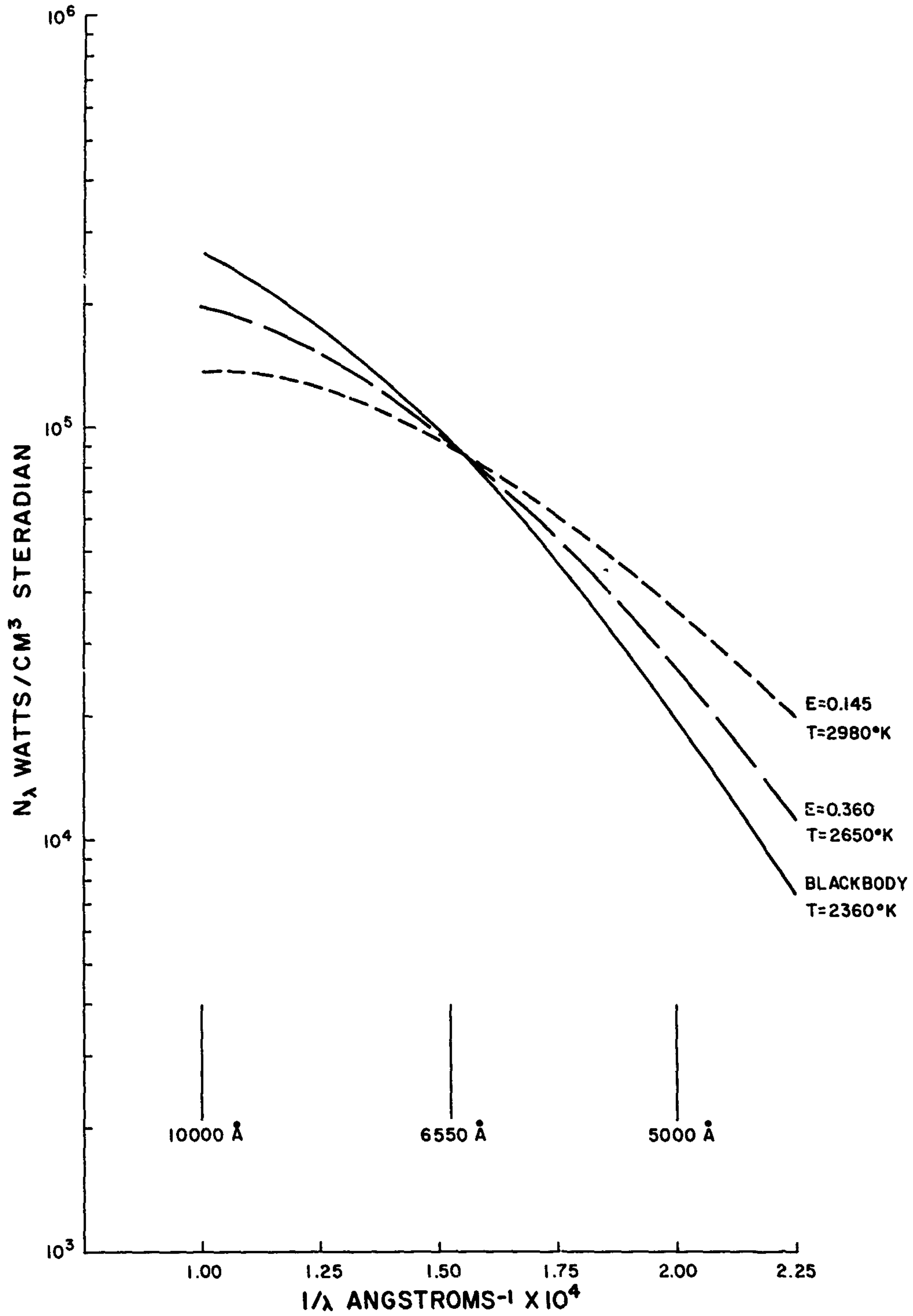


Figure 13. Comparison of the Spectral Distribution of the 1% and 20% Ceria Mantles with the Blackbody Distribution; Mantles Operated at Brightness Temperature of 2360°K

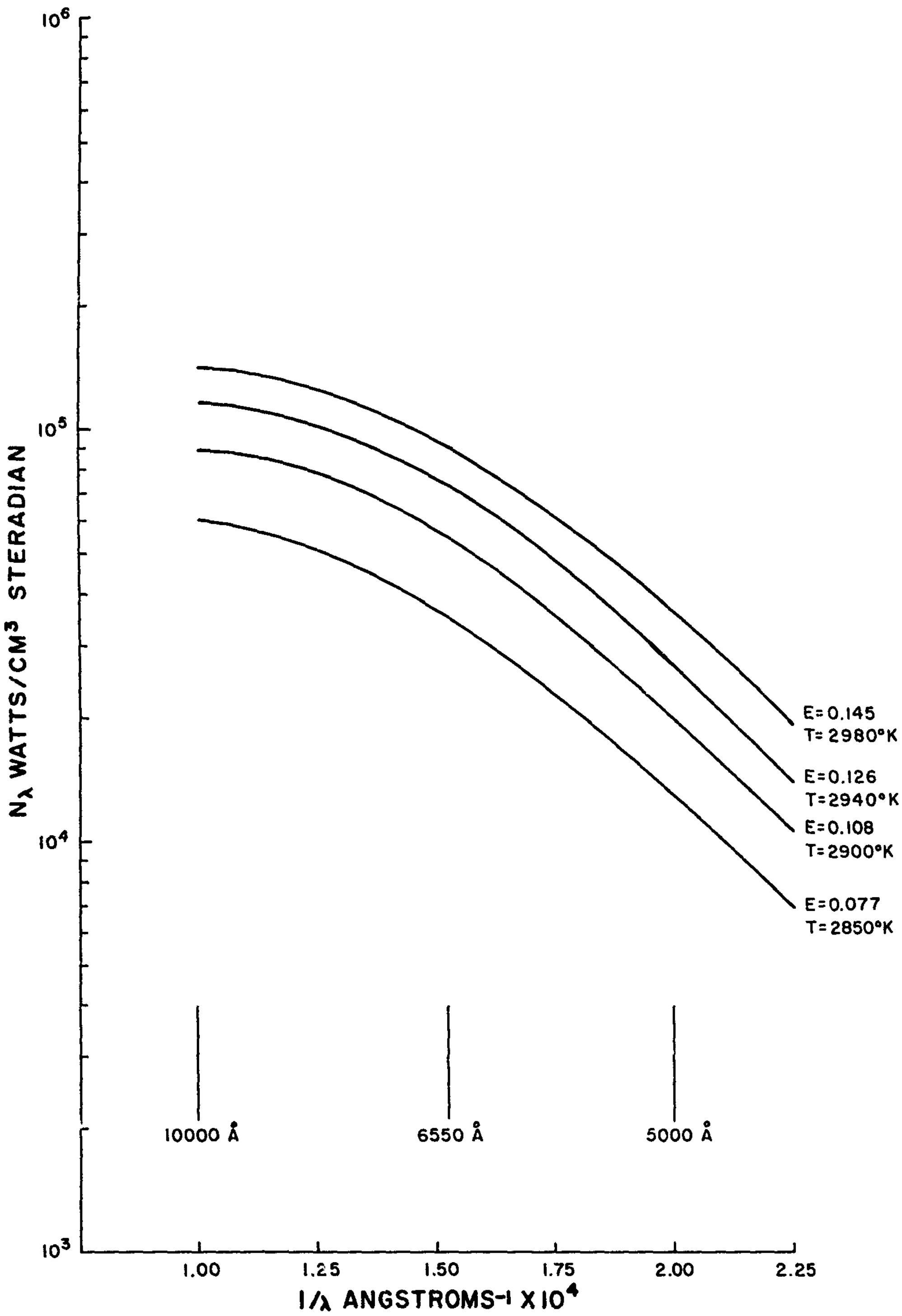
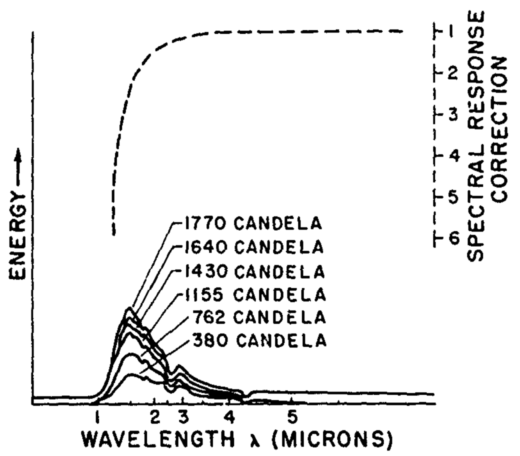
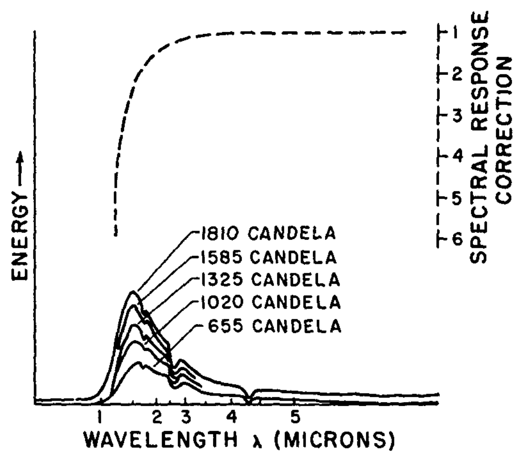


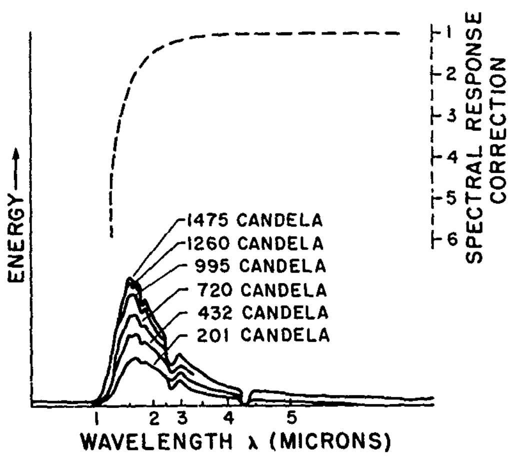
Figure 14. Determination of Operating Temperature and Emittance of the 1% Ceria Mantle based on Spectral Distribution of the Illumination



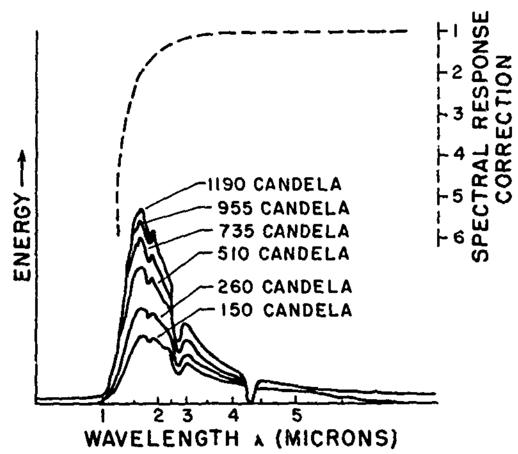
a - 1% Ceria



b - 5% Ceria



c - 10% Ceria



d - 20% Ceria

Figure 15. Mantle Spectral Comparison 1%, 5%, 10% and 20% Ceria

the spectral energy distribution of the mantle and to attempt to define the operating temperature of the mantle.

a. Spectral Distributions from 0.4 to 1 micron

A series of four spectral energy determinations were made on each of the four mantle compositions. These determinations were made using a McPherson 0.3 meter, grating spectrograph. The grating was blazed at 5000 angstroms and the photomultiplier used as the detector had an S-1 spectral response. The apparatus, including the collection optics, was calibrated with an N.B.S. standard lamp having a known spectral distribution. The experimental procedure was to image the mantle on the slit plane of the spectrograph, set the fuel rate, adjust the oxidizer flow rate to obtain maximum candlepower, and then record the brightness temperature of the mantle and the spectral distribution. The fuel rates for each mantle composition tested were:

6,700 Btu/hr (propane)
9,000 Btu/hr
11,300 Btu/hr
13,700 Btu/hr

The spectral distributions so obtained are presented in Figures 12a to 12d. These distributions are comparable in amplitude with the following qualification: the mantle surface area falling on the slit was unknown. The slit opening was 50 microns wide and 10 millimeters high. The image of a discontinuous surface (the mantle weave) was focused on the slit plane, but there was no way to obtain a known or even a constant area of the excited mantle surface falling on the slit opening. This, of course, was due to the filament or thread type construction of the mantle. Thus, to the extent that the mantles had the identical weave and gauge, the spectral amplitudes are comparable. This condition was less important in the infrared determinations because the slit width was 10 times wider. The distributions presented show two important features of the nature of the radiation obtained from the mantles:

1. The radiation is continuous with no evidence of a contribution from the flame and no evidence of non-equilibrium phenomena such as thorium or cerium oxide molecular band heads superimposed on the continuum.

2. The spectral distribution of the radiation shifts toward the red end of the spectrum with increased ceria content of the mantle. This fact clearly explains the results obtained in the performance testing (candela versus fuel rate, Part A) in which the one percent ceria mantle always operated with the highest candela output.

Since the area of the radiating source was undefined, it was not possible to generate an ordinate in terms of spectral radiance for the distribution presented; however, the following procedure, illustrated in Figures 13 and 14, largely compensates for this deficiency. The brightness temperature of the mantle was obtained for each spectral determination; this temperature defines the spectral radiance of the surface at 6550 angstroms. The spectral distributions recorded relate the radiance at any other wavelength (in the interval from 0.4 to 1 micron) to that at 6550 angstroms. Therefore, assuming a unit area of radiating surface, a plot of spectral radiance versus wavelength can be obtained. Figure 13 shows the most interesting results of such a procedure. The distributions obtained for the 1% and 20% ceria mantles are shown in terms of radiance versus reciprocal wavelength. Both mantles were operated at a brightness temperature of 2360°K, the solid line in the plot. Each mantle must have the same spectral intensity at 6550 angstroms as defined by a blackbody at 2360°K; hence the cross-over point at that wavelength. Since both the spectral emittance and the operating temperature of the mantle were unknown (but are independent functions which together define the spectral radiance), an iterative procedure, assuming constant emittance, was employed to attempt a fit for each of the mantle distributions. It was discovered that the distributions shown would be exactly reproduced by radiation sources operating at 2980°K ($\epsilon = 0.145$) and 2650°K ($\epsilon = 0.36$) corresponding to the 1% and 20% ceria mantles, respectively. While it is recognized that a fit can also be obtained by choosing any temperature above certain limiting values[8] and assuming that emittance varies continuously, becoming smaller with increasing wavelength, it seems possible to now consider that the emittance is nominally constant throughout the interval.

[8]The limiting values are 2520°K for one percent ceria mantle and 2400°K for the 20 percent mantle. These temperatures are defined by an emittance of unity at 4500 angstroms and the measured spectral radiance at that wavelength.

Figure 14 presents the family of spectral representations of the 1% ceria mantle that was obtained at the four specified fuel rates. These curves can be reproduced to a high degree of accuracy ($\epsilon = \pm 0.01$) by the combination of ϵ and T listed for each curve. The combinations are:

TABLE V. TEMPERATURE AND EMITTANCE DETERMINATION FOR 1% CERIA MANTLE

Fuel Rate Btu/hr	Temperature °K	Emittance
13,700	2980	0.145
11,300	2940	0.126
9,000	2900	0.108
6,700	2850	0.077

These temperatures appear to be too high until it is considered that the adiabatic flame temperature for the reaction is approximately 3100°K. As a result of these experiments and other supportive evidence (described in Section IV), it is postulated that the tabulated temperature-emittance values are representative of the actual properties of the mantle when it is excited in a flame. The "mechanism" for the mantle's luminous intensity is that the equilibrium operating temperature of the mantle approaches the adiabatic flame temperature of the exciting reaction. This postulation and mechanism are the subject of discussion in Section IV of this report.

b. Spectral Distributions from 1 to 5.5 microns

The infrared spectral distributions of the family of mantle compositions were examined by exciting the test mantle at six separate fuel rates (hydrogen) and recording the spectral distributions on a Perkin-Elmer Rapid-Scan Monochromator. The detector used in these experiments was the Indium-Antimonide PEM device operating at room temperature. Figures 15a through 15d present the results of these determinations. Each figure includes an amplitude correction factor as a function of wavelength that accounts for the spectral response of the

complete monochromator system. This format was used in order to preserve the detail of the spectra that would be lost in graphically correcting for system response. The relative amplitude of the spectra in each compositional group is comparable as well as being comparable from group to group. For these tests, the hydrogen fuel rate was set and the oxygen added to maximize candela output. This procedure forced the reaction to operate oxygen rich and this accounts for the 10 percent to 20 percent decrease in candela recorded for specific fuel rates.

The fuel rates for each mantle composition tested were:

1,800 Btu/hr (hydrogen)
4,400 Btu/hr
7,000 Btu/hr
9,100 Btu/hr
11,000 Btu/hr
13,000 Btu/hr

The main features of these spectral distributions can be summarized as:

1. Each group of distributions shows the expected shift of the peak radiance toward the shorter wavelengths as the fuel rate is increased. This effect is diminished by the sharp fall-off in system response in the range of one to two microns but it is still readily observable. It should be emphasized that the fall-off in response distorts the spectra presented. Figures 12a through 12d show that the radiance of each mantle is essentially the same at one micron for comparable fuel rates. This fact indicates the extent of this distortion.

2. The spectral radiance is strongly dependent on the ceria content of the mantle, increasing as the ceria content increases.

3. There is no evidence of water emission in the spectra except at the lowest fuel rate where it may be seen at 2.4 microns. This lack of emission at the higher fuel rates strongly suggests that the mantle is in equilibrium with the flame. If the mantle is in equilibrium with the flame, it has important implications in terms of the true operating temperature of the mantle. These implications are considered in Section IV.

B. Applications-Oriented Experimentation with the Mantle

Several specific experiments were undertaken in order to develop information on the practical operation of the oxygen-fired mantle. These experiments had two separate objectives:

1. To explore the operation of an array of mantles in terms of combustor requirements and mantle performance, and

2. To explore the operation of the mantle and combustor in combination with a small reflector.

Before a description of this work is presented, a summary of a group of experiments that serve to identify constraints for mantle operation is appropriate.

Mantle life - When the #846 mantles were operated at the maximum propane fuel rate, 13,700 Btu/hr, it was noted that the illumination decreased as a function of time. Investigation showed that the decrease in output was as high as 25 candela/minute. This decrease in performance was identified with a loss of mass from the mantle. The ceramic fibers appeared to have sublimed. Testing with hydrogen, however, indicated that the loss of mass was associated with mantle participation in the fuel oxidation process. The participation, in turn, was a function of the completeness of the reaction within the mantle volume. The required reaction volume, defined by the mantle volume, had been exceeded when the #846 mantle was operated at 13,700 Btu/hr. In support of this conclusion, it was found that the #846 did not deteriorate measurable at 11,000 Btu/hr nor did the #848 (the larger mantle) deteriorate measurably at 13,700 Btu/hr. The chemical participation by the mantle was found to be strongly a function of operating temperature; a fuel rich operation was possible if the operating temperature (brightness) was maintained below 2200°K.

Spatial Distribution of the #846 Mantle Illumination - A series of tests was conducted to determine the spatial distribution of the mantle illumination, using both propane and hydrogen over the usual range of fuel rates. The mantle viewing angle was varied from 7 to 67 degrees (starting just above the horizontal and moving toward the vertical), and it was found that the illumination could be considered as independent of aspect angle. Within the range of the viewing angles tested, the

tabulated values for luminous intensity are appropriate for the 1, 5 and 10 percent ceria mantles fueled with either hydrogen or propane.[9]

Large Mantle Operation - Several types of soft mantles having large candlepower ratings, (rated by the manufacturer for operation with premixed air and fuel) were tested using combustor Design #2. A typical example of this type operation is illustrated in Figures 16 and 17. Figure 16 shows the mantle, rated at 2000 candlepower, after it was formed and hardened by firing with an air-fuel reaction. The mantle was approximately 1.5 inches in diameter and four inches long. Figure 17 shows the mantle in operation at 7500 candela with a fuel rate of 60,000 Btu/hr (H_2).[10] This mantle was underfired and not fully excited at this operating point. It should be noted, however, that the mantle has begun to sag under its own weight at this level of operation. If the apparatus were designed to operate inverted, the mantle could be operated at twice the fuel rate, because the mantle would not deform. The principle problem in the operation of the mantles in the inverted mode is that provision must be made to sweep the products of reaction away from the combustor apparatus. In the example above, some 100 cubic feet of high temperature products are released per minute; the cooling design for this level of operation was beyond the scope of this experimentation.

Smaller soft mantle sizes (400 and 800 cp) were tested, and the performance was found to be consistent with the approximation; 5 Btu/hr/candela for hydrogen fuel. All of the soft mantles were mechanically inferior to those that were hardened in the manufacturing process. These results strongly suggest that larger mantles be of the hardened type and be operated in the inverted mode.

1. Mantle Operation with a Reflector - In order to efficiently couple a reflector to a vortex driven mantle, modification was necessary in the combustor design to obtain some degree of profile streamlining. The design chosen (see Figures 1 and 18) was one in which the fuel was introduced into a single vortical flow field through a peripherial slot at the exit of the combustor. It was found that the radial feed was effective in providing the necessary mixing for good mantle performance.

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[9]See Table II and Figure 10.

[10]The exposure was f/32 at 1/150 sec, ASA 50 Polaroid.

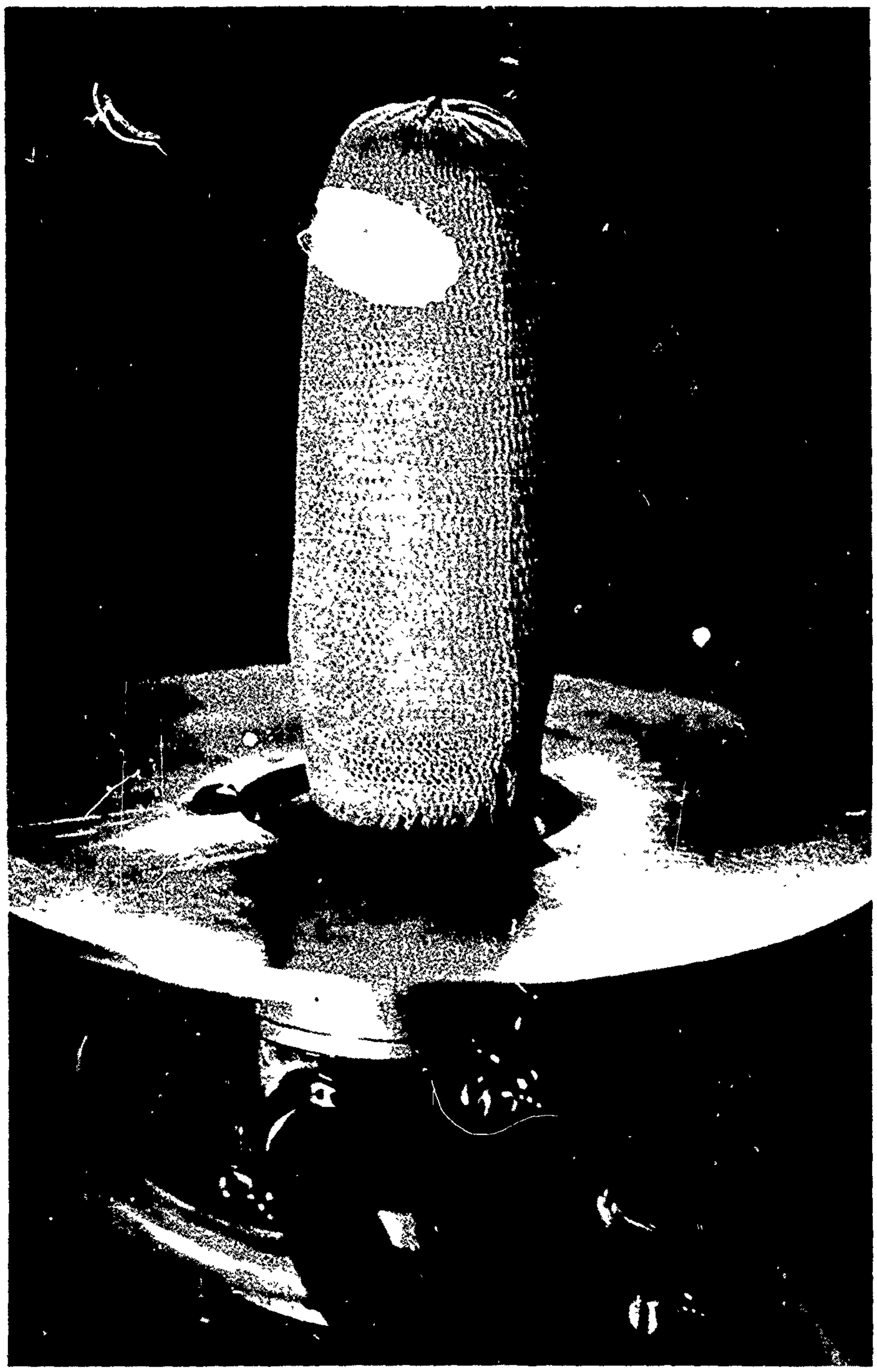

Figure 16. 2000 Candlepower Mantle before Firing

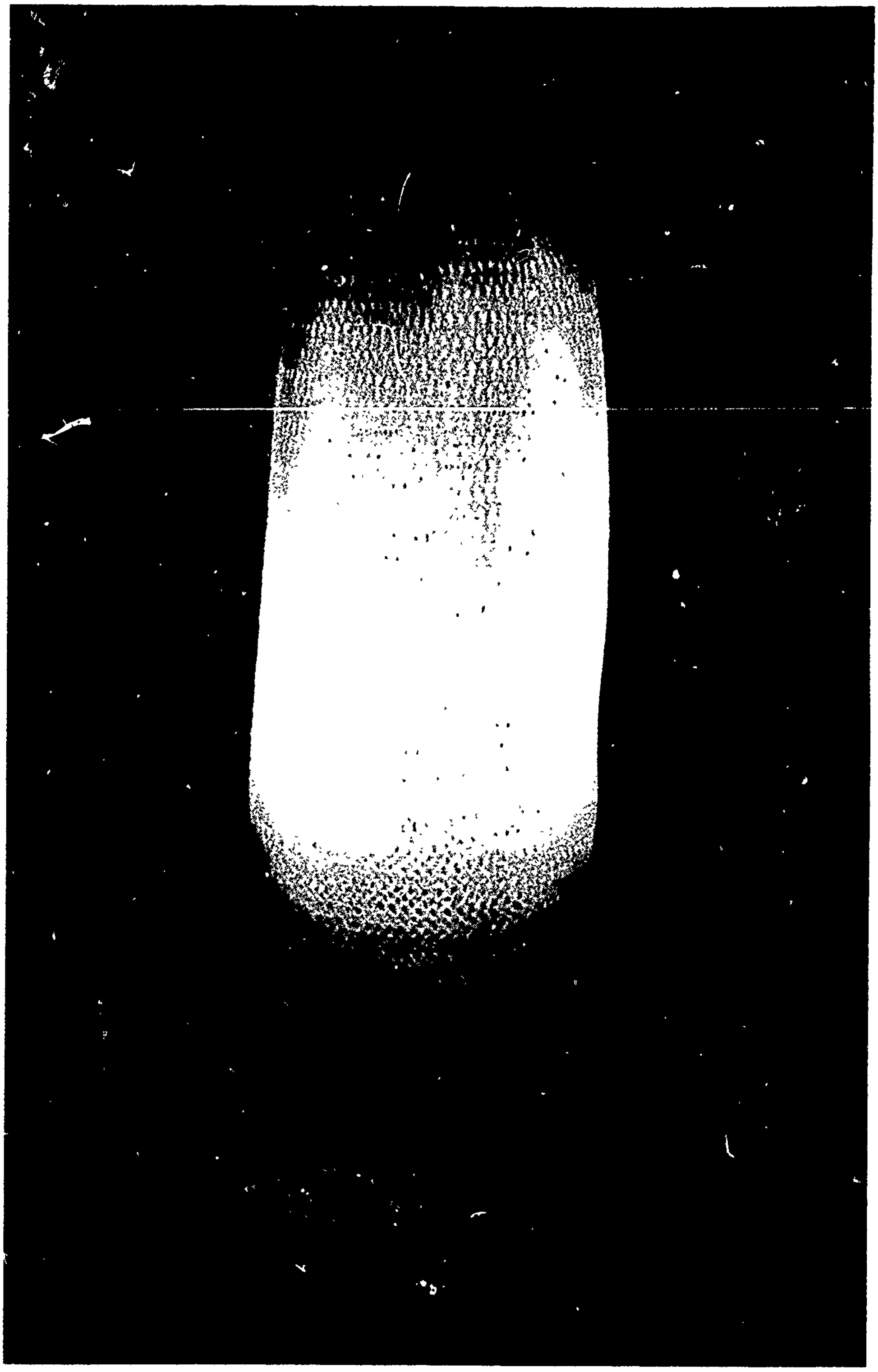

Figure 17. Mantle Operating at 7500 Candela

The apparatus is shown in Figure 18 and the performance obtained with this combination is detailed in Figure 19. The five propane fuel rates normally employed in testing were used to generate the illumination profiles presented. The reflector used in this experiment was from a "Veritas G1908 Major Floodlight", a commercially available item. The mantle used was the standard #848. As can be seen in the performance plot, a 10° cone of illumination in excess of 50, 000 beam candlepower is formed by the geometry. This experiment successfully demonstrated the potential of the oxygen-fired mantle as a practical, high intensity source of illumination.

2. Combustor Arrays - The operation of mantles in arrays or groups was undertaken in order to investigate two questions:

1. Is there any deleterious interaction between mantles when operated immediately adjacent to one another?

2. Could multiple mantle operation be demonstrated in which the mantles were oxygen-fired and in a compact geometry?

The mantle array illustrated in Figure 20 was the first one constructed in order to explore multiple mantle operation. Eight separate vertical combustor units (Design #3) were assembled in an octagonal configuration as shown. The back plate of the apparatus was water cooled and product condensation may be seen in the photograph. The ceramic rings previously described (Section II) may be seen at the base of the mantles.

This configuration demonstrated a major difficulty in mantle operation; a new mantle tends to sag when excited for the first time in a position other than upright or inverted. If, however, the mantle is first fired in the upright position and then turned sideways, the sag is observable but not serious. The maximum candela obtained from this apparatus, operated on propane, was 33, 000 candlepower viewing the apparatus head on. At 30° off the centerline, the illumination decreased to 75 percent of the centerline value.

The first evidence of interaction between the mantles of the array was indicated by the buildup of carbon on the lower part of the mantles in the array. This buildup was initially interpreted to be the result of underoxidization and it remained misunderstood until the second array was tested.

Figure 18. Floodlight Apparatus

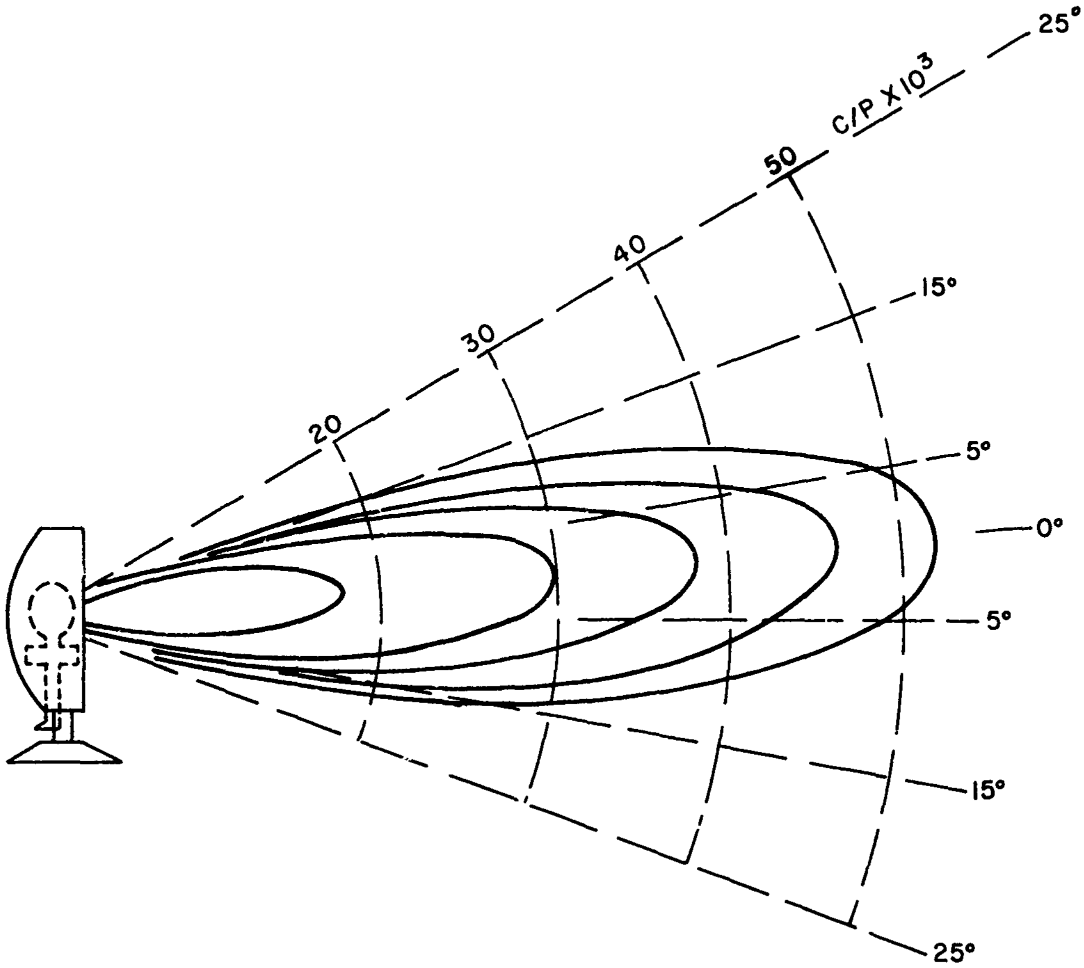

Figure 19. Beam Candlepower Distribution of the Mantle-Reflector Combination (Reflector is 14 inches in diameter). The envelopes are associated with fuel rates that range from 4500 to 13, 500 Btu/hr

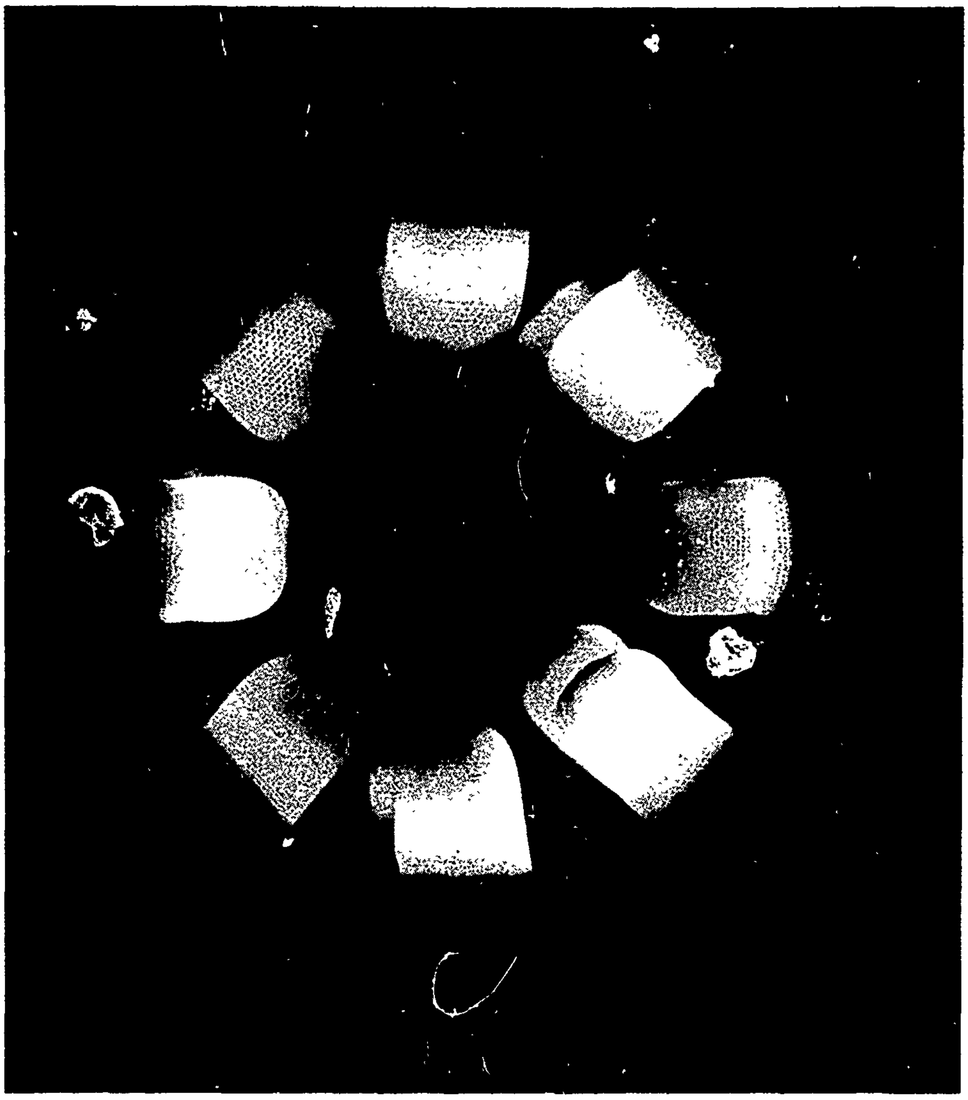

Figure 20. Octagonal Mantle Array

The second array presents another approach taken in the investigation of multiple mantle operation. The apparatus used in this approach was the design pictured in Figures 21 and 22. The eight vortices are located on a 5-inch diameter circle; oxygen is introduced through the tangential inlet while the fuel is introduced through the central pipe at the back of the apparatus. A water cooling jacket was also included in the design. The apparatus is essentially eight of the Design #3 combustors in a single unit. This combustor had the advantage that all the mantles could be operated in the vertical or upright positions.

Testing of this array with #848 mantles gave results that were poorer than those obtained with the first array. Again, there was carbon buildup at the bottom of the mantles and there was no possibility that this condition resulted from a simple lack of oxygen. The performance was approximately one-half that expected. At a fuel rate of 13, 000 Btu/hr per unit, the array generated 10, 000 candela when the expected output was 20, 000 candela. The decrease in performance was finally tied to the fact that the circulation that is established within a mantle when operated alone was cancelled when the mantles were operated in the array. The walls of the mantles in the array were approximately 1/2 inch apart; since the rotation of the dominant vortex (oxygen) was in the same sense for each unit of the array, the rotational flow vectors at each pair of mantle walls were opposite in direction and the circulation within the mantles was diminished in proportion to the interaction between the rotational flow vectors. The loss of circulation within the mantle accounted for the carbon buildup seen in the testing of both arrays. Verification of this interpretation was obtained by operating a single unit of the array; at a fuel rate of 33, 000 Btu/hr, the single mantle generated 5500 candela. This value is consistent with the 5.3 Btu/hr/candela previously established for the #848 with propane.[11]

The work with the mantle arrays led to two major conclusions that have a bearing on the design for multiple mantle operation:

1. Mantle orientation, either upright or inverted, is necessary in order to avoid sagging of the mantle during startup, and

2. Circulation within the mantle is very necessary for the establishment of mantle performance.

[11]There was, however, evidence of mantle deterioration at this fuel rate.

Figure 21. Disk Array

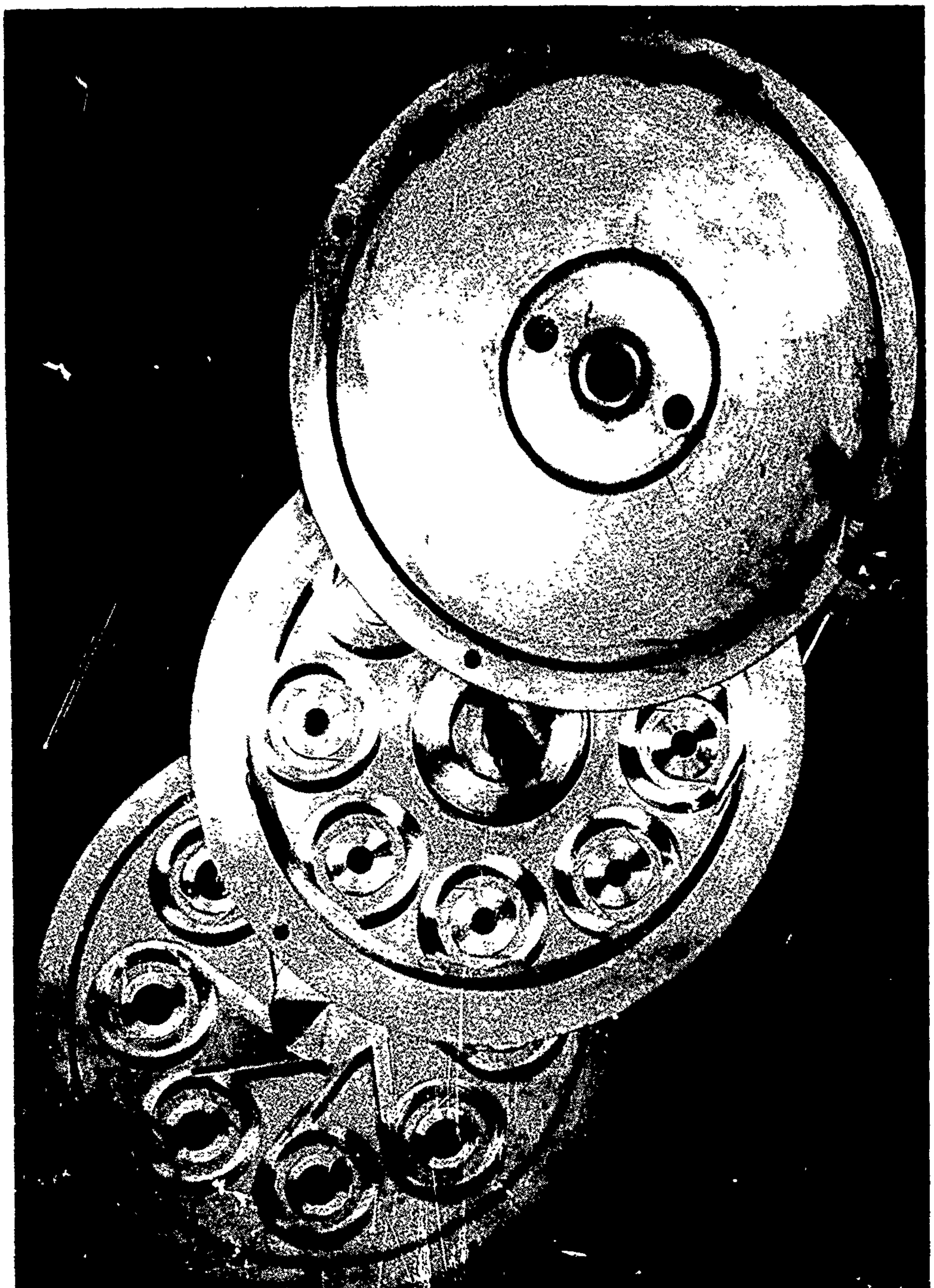

Figure 22. Internal Design of Disk Array

The questions that prompted the investigation of multiple mantle operation can be answered as follows:

> There is an interaction between a group of mantles closely coupled. This effect may be overcome by intensifying the strength of the oxygen vortex or by changing the sense of rotation of alternate units so that the rotational components of the flow add rather than subtract. Satisfactory multiple mantle operation was not demonstrated, but it is believed that the important considerations have been identified and that multiple operation could be achieved in a combustor design that responds to these considerations.

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Section IV

A MODIFIED THEORY OF MANTLE OPERATION

The theory of mantle operation that has received the most attention through the years is that of Ives, Kingsbury and Karrer.[12] In their study, the authors determined that the addition of small amounts of cerium oxide to a thorium mantle changed the spectral emittance of the combination such that the emittance at 0.7 microns was approximately 0.20 while at 0.4 microns it was 0.75.[13] This characteristic was common to a system of rare-earth oxides that were described as "oxides of high emissive power in the visible". They postulated that the thorium oxide, having low emittance, receives energy from the flame and transfers it to the cerium oxide which then radiates with the high emittance characteristic in the visible. The low overall emittance characteristic of the thorium oxide allows it to achieve a high temperature in the flame and the cerium oxide then radiates from the high temperature reservoir. In the development of this theory, much attention is given the fact that the mantle undergoes a color change when heated; the initially white mantle changes to a yellowish color as a mantle is introduced into a flame. With increasing ceria content, the yellow color becomes more pronounced. This yellowing is identified as selective absorption band in the visible and the emittance characteristic previously described is understood as the same band, but in emission.

This comprehensive development hinges on a single determination - the actual temperature of the mantle. In the study, temperature was determined by the method of extrapolation to zero thermocouple - wire size. This technique is generally excepted as a valid method of establishing the actual temperature of a radiating body. However, before exploring whether or not the method was valid in this case, the effect that an error in the determination of the actual mantle temperature has on this theory of mantle operation will be examined.

At the blue end of the visible spectrum, the radiance of a source varies as the 15th power of the source temperature assuming that the emittance is constant over the range of temperature examined. This

[12]Herbert E. Ives, E. F. Kingsbury, and E. Karrer, "A Physical Study of the Welsbach Mantle", Journal of the Franklin Institute, Vol. 186, October 1918.

[13]Based on a temperature measurement of 1870°K.

corresponds to the spectral region in which the family of oxides displays the characteristic of "high emissive power".

Table VI presents a tabulation of the spectral emittance characteristic as a function of assumed temperature that is based on the spectral distribution of the 0.75 percent ceria mantle as determined by Ives.

TABLE VI. EMITTANCE VERSUS WAVELENGTH FOR THREE ASSUMED TEMPERATURES

Wavelength Microns	Assumed Temperatures 1870°K	2000°K	2100°K	2200°K
0.4	0.76*	0.21	0.09	0.04
0.5	0.68*	0.23	0.11	0.06
0.6	0.26*	0.11	0.06	0.03
0.7	0.20*	0.10	0.06	0.04

*Data presented by Ives, based on a measured temperature of 1870°K.

This table shows that the mantle need not be an emitter of unusual spectral characteristic; i.e., having a high emissive power in the visible region of the spectrum, it need only have a low emittance (not necessarily constant) but be operated at high temperature. At a temperature of 2100°K, the unusual spectral emittance is all but unrecognizable and at 2200°K it is entirely reversed. The concept of a high emissive power was originally offered by Rubens in 1906, it was further developed by Ives in 1918, repeated in 1927 by Ewest, and again by Smith in 1941. The fact is that any temperature measurement of an operating mantle with a thermocouple will have to be too low, and the whole idea of "high emissive power in the visible" loses value if the temperature determination is low by more than 50°C. It is this author's contention that the actual temperature of the mantle described in the table above was approximately 2100°K instead of 1870°K.

The reasons for this contention are threefold:

1. Ives estimated that the flame temperature of the coal and water gas reactants used was approximately 2100°K; this estimate served as an upper limit in the development of the theory. The actual flame temperature for the reactants used is approximately 2200°K.[14]

2. Ives determined the spectral emittance of pure thorium oxide to be approximately 0.01 in the wavelength range of one to six microns. But below one micron the emittance of this oxide also increased sharply, reaching 0.1 at 4000 angstroms. This is the same behavior seen with the ceria added, just a factor of 10 smaller in amplitude.

3. The difficulty in obtaining valid temperature determinations using a thermocouple in this instance is enormous. While the procedure employed was correct, no consideration was given the possibility that the thermocouple was not in equilibrium with the mantle. Such an equilibrium should not be expected because the thermocouple and mantle fibers are of the same size and heat capacity but the ceramic fiber has approximately 1/100 of the thermocouple's heat conduction coefficient. Assuming good thermal contact between the fibers of mantle and the thermocouple, one would expect a gradient to exist across the fibers. With poor thermal contact, one would expect that the temperatures reported approximate the temperature of the products of reaction.

This work has been discussed in detail because it sets the stage for a departure in the interpelation of the "mechanism" of mantle operation. It was postulated in Section III that the emittance of the 1% ceria mantle was nominally constant for a specific temperature and that the operating temperature of the mantle was quite high approaching the adiabatic flame temperature of the reactants. While there was no means for establishing the true temperature of the mantle and thus making the theory definitive, there were several courses of action open. The first was to examine the work of Ives in order to determine whether or not a nominally constant emittance assumption could be consistent with his results. Table VI shows that this is possible and the explanation that

[14] B. Lewis, H. Seaman and G. W. Jones, J. Franklin Institute, 215, 199 (1933).

followed indicates why the measured temperature can be considered somewhat low.

The next step was to examine the infrared spectra to ascertain if the products of reaction were in equilibrium with the mantle. It was found that this was the case as the fuel rate was increased toward 13,000 Btu/hr. The fact that equilibrium is approached with increasing fuel rate does not define the operating temperature, but if the products did not approach equilibrium with the mantle it would invalidate the high operating temperature postulate. Finally, total radiation values were compared with the thermochemical properties of the reaction products. Assuming equilibrium between the mantle and reaction products, the temperature of the products should be controlled by the energy radiated by the mantle. The 1% ceria mantle radiates approximately 100 watts/steradian (type #846, viewed from the side) at a fuel rate of 13,700 Btu/hr. The total radiation from the mantle geometry is approximately 700 watts; there are approximately 1200 watts available when the products are cooled to 2750°K (including losses to the combustor). This comparison indicates that the product temperature must be higher than 2750°K.

While the data presented in Figures 13 and 15 show a nominally constant emittance, this feature should not be over-emphasized. The important concept is that the emittance is low, becoming higher at slightly higher temperatures. The emittance is certainly not constant over the whole spectral range and is probably represented quite accurately by Ives beyond one micron where the radiance is much less sensitive to a discrepency in actual temperature. In plots similar to Figure 13 for the 5 and 10% mantles, the fit was not as good as those shown; this fact indicates that the emittance does vary but on the order of ±0.04.

Section V

CONCLUSIONS AND RECOMMENDATIONS

The potential of the vortex-driven mantle as a source of high intensity illumination has been clearly demonstrated. A continuously operating source both of high intensity and chemically driven has been developed. The efficiency of this source is approximately 10,000 candle-second per gram of reactants and the source can be continuously operated to give an intensity of 3500 candela (using hydrogen at 22,000 Btu/hr and the #848 mantle). These mantles, which have 1.75 square inches of projected area, are small enough to have good mechanical properties and large enough to be used in an array that would generate substantial illumination without the number of units required causing any great difficulty.

The requirements for the successful operation of a compact array of mantles have been identified and successful operation of the oxygen-fired mantle in a small reflector has been demonstrated also.

A modified theory of mantle operation has been presented in which the "mechanism" of mantle performance is identified with low emittance and high operating temperature. This insight suggests that the performance of the mantle might be improved still more by the use of cyanogen-oxygen reactants since there is evidence that the emittance of the mantle increases with operating temperature. The melting temperature of the thorium oxide is approximately 3300°K (the trace amount of cerium oxide would not be expected to affect the melting temperature); the difference between this temperature and the inferred operating temperature (2980°K) is great enough to offer considerable improvement.

The greatest drawback to the use of the mantle lies in its lack of mechanical strength. A serious effort should be undertaken to explore the possibility of attaching the mantle fibers to a rugged substrate. If the fibers were oriented in a cavity, something like a velvet lining in a bowl, the ends of the fibers could be excited while the fibers themselves provide the insulation between the substrate and the high temperature environment. A design of this type could be readily excited using existing vortical combustion techniques.

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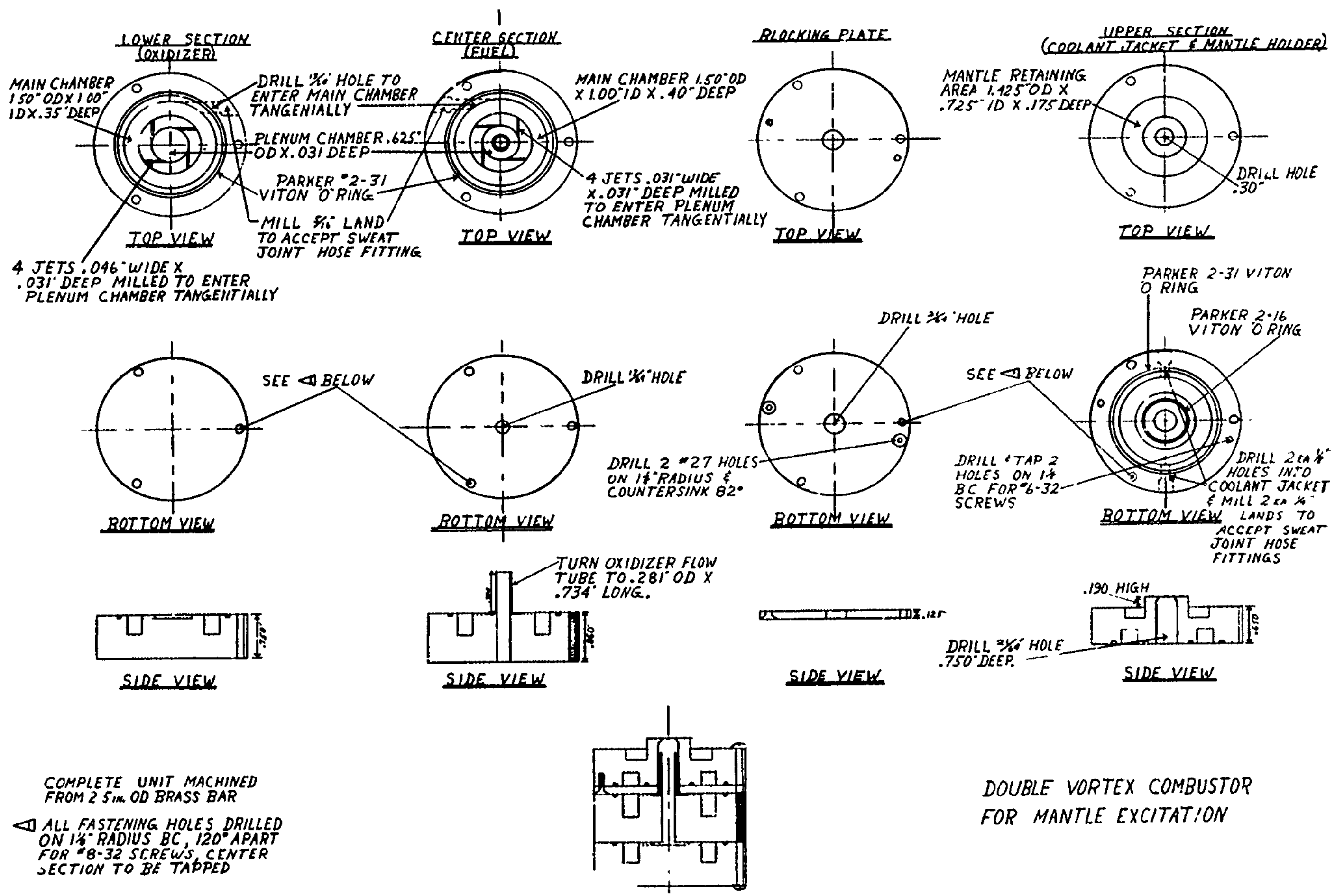
Appendix I

LINE DRAWING OF COMBUSTOR
DESIGN #2

GRAPHIC NOT REPRODUCIBLE



DOUBLE VORTEX COMBUSTOR FOR MANTLE EXCITATION

Appendix II

INSTRUMENTATION

Flow Measurement

The primary flow meters were the Fischer and Porter "Triflat Variable - Area Flowmeters". These units (in four sizes) were operated at 20 psig and were supplied from regulated bottle gas sources.

Temperature Measurement (brightness)

An optical pyrometer, Leeds and Northrop 8662C, was used. This pyrometer is the "disappearing" filament type with a mean effective wavelength of 6550 angstroms.

Spectral Distribution

From 0.4 to 1 micron, a McPherson 0.3 meter, grating spectrometer was used. The grating was blazed at 5000 angstroms, and the photomultiplier detector has a S1 spectral response. The spectrometer, Model 218, has a resolution of 0.6 angstroms, and was calibrated using a standard lamp (having an N.B.S. certificate) for spectral response.

From 1 to 5.5 microns, a Perkin-Elmer Model 108 rapid-scan monochromator was employed. The detector, the indium-antimonide PEM type, was operated at room temperature. The spectrometer system including foreoptics and detector was calibrated with a carbon arc source which operates as a blackbody at 3820°K.

Foot-candle Meter

This device was a selenium photovoltaic cell filtered with a Wratten 102 transmission filter. This combination is accurate to ± two percent, as determined by cross-checking against the N.B.S. standard lamp and secondary standards.

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13. ABSTRACT

The potential of the Welsbach mantle as a means for producing high intensity illumination has been examined. Through the development of a vortex combustor geometry that drives the mantle, and the substitution of fuel-oxygen reactants for the normal fuel-air combination, the luminous intensity of the mantle was increased 30 to 50 times. An efficiency for the conversion of chemical energy to illumination of 0.2 candela/Btu-hr was achieved.

The mechanism for the production of light from a mantle was investigated by evaluating the changes in performance obtained with mantles having various thoria-ceria ratios. These studies lead to the proposal that the mechanism for light production lies in the combination of low emittance and high temperature rather than in a "high emissive power in the visible" as the phenomena have been described.

Various combinations of mantle arrays have been investigated in order to define the requirements for multiple mantle operation in compact configurations. This work was extended to the investigation of the oxygen-fired mantle in combination with a small reflector. The combination was used to generate a 10° cone of illumination in excess of 50,000 beam candlepower with an efficiency of four candlepower/Btu-hr. ( )

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